

USAF ETAG TN 70-1

# ENVIRONMENTAL *Technical Applications Center*

TECHNICAL NOTE  
70-1

AD700052  
ETAC

A  
SELECTED ANNOTATED BIBLIOGRAPHY  
ON  
CLEAR AIR TURBULENCE (CAT)

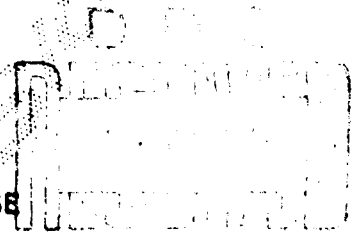
Compiled by  
Alvin L. Smith, Jr.  
and  
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JANUARY 1970

METEOROLOGICAL



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### Purpose

USAF ETAC Technical Notes are published by the USAF Environmental Technical Applications Center to disseminate aerospace sciences information to units of the Air Weather Service. Subject matter contained in these Technical Notes, while pertinent, is not deemed appropriate for publication as Air Weather Service Technical Reports which are confined to those studies, reports, techniques, etc., of a more permanent and specific nature. Technical Notes include such material as wing seminar listings, bibliographies, special data compilations, climatic studies, and certain USAF ETAC project reports which may be of special interest to units of the AWS organization. This series is published under the provisions of AFR 6-1 and AWSR 80-2, as amended.

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## PREFACE

One of the primary functions of the Technical Information Section of the USAF Environmental Technical Applications Center (ETAC) is to locate reference material requested by the various governmental agencies and those civilian organizations completing government contracts. The requests are generally initiated to aid in the solution of specific problems. However, many of these bibliographies represent a substantial listing of pertinent sources which, having been compiled, could prove very beneficial to other researchers with similar interests in subject matter or area of coverage. It is with this in mind that USAF ETAC publishes certain reference listings such as this bibliography. It is believed that, by publication and distribution of these consolidated reference lists, much of the time-consuming reference-searching of the researcher can be eliminated.

Inclusion of an item in this listing does not constitute an indorsement of the information included therein by the DOD, USAF, Air Weather Service, or USAF ETAC. It also must be noted that references selected for this bibliography should not be construed as being the best or only references available as many excellent papers, reports, etc. were no doubt overlooked during the limited search period allotted the author for this project. It is believed, however, that the listing contains a cross section of studies from many of the leading researchers in the Clear Air Turbulence programs.

This document has been approved for public release and sale; its distribution is unlimited.

## INTRODUCTION

This bibliography was compiled as a by-product of the regular reference-searching that characterizes the normal workload of the Technical Information Section, USAF ETAC. Most of the abstracts were taken from the publications themselves, many from Meteorological and Geostrophysical Abstracts, published by the American Meteorological Society, and others were obtained in a Report Bibliography Search on Clear Air Turbulence prepared for ETAC by Defense Documentation Center for Scientific and Technical Information, Cameron Station, Alexandria, Virginia.

The items selected for this listing refer to Clear Air Turbulence, for the most part, although several references are included pertaining to Critical Air Turbulence and turbulence in and around clouds. Further, only references to Clear Air Turbulence as it occurs in the atmosphere are shown; laboratory models and/or research, for the most part, are not referenced.

A general sampling of the articles by authors worldwide is the main theme of this bibliography. Articles selected may not always be the best article written by that author, however, from a selection of several hundred references considered, these seem to fairly well illustrate the general knowledge of Clear Air Turbulence, its problems of detection, avoidance, characteristics, etc. at various levels in the free atmosphere. Nevertheless, in a search of this magnitude, some authors may have been overlooked and apologies for such oversights are hereby offered. The author in no way implies in this bibliography that one reference and/or author is better than any other, but offers these references as a general compilation of works on Clear Air Turbulence published during the 1964-69 period.

In 1968 the Department of Defense published the "DOD National Program for Clear Air Turbulence, Development Plan". Within this plan responsibilities for certain areas of critical air turbulence were delineated. Altitude ranges were designated for specialized study with the following nomenclature assigned:

ALLCAT MOCAT	}	-	Overall Classifications
TOLCAT	-	-	Surf to 250 ft above ground
LO LOCAT	-	-	250-1000 ft above terrain
LOCAT	-	-	1000-20,000 ft altitude
MEDCAT	-	-	20,000-40,000 ft altitude
HICAT	-	-	40,000-70,000 ft altitude
HI HICAT	-	-	70,000 to 200,000 ft altitude
TOPCAT	-	-	Project over Australian area

Several items listed in this bibliography are either the indirect results of these designated projects or are actual monthly, interim, or final reports of contractual arrangements of the DOD program. These references are shown below, by number, opposite the altitude code name with which they are associated.

ALLCAT	114, 149, 180.
LO LOCAT	118, 136, 146, 147, 148, 152, 191, 209, 210.
HI CAT	27, 64, 78, 108, 112, 164, 182, 184.
HI HICAT	63.
TOPCAT	11, 13, 24, 60, 89, 90, 103.

A very few items by foreign author are shown as being in a language other than English. Where a known translation exists, the translation information is included. It may well be, however, that the foreign language entries found herein do indeed exist in an English version, unbeknown to the author.

References in this bibliography are listed alphabetically within each year of publication (1964-1969). All references list a source at which the item may be located either by library accession number, AD number, or other indicator. Generally, most references may be obtained in the Washington area. Abbreviations denoting various libraries are identified under Index to Source Symbols below.

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Index to Source Symbols

CFSTI	Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.
DAS	Atmospheric Science Library, Silver Spring, Maryland.
DAS P Col	Periodical Collection, Atmospheric Sciences Library, Silver Spring, Maryland.
IPB	Information & Publications Branch, USAF ETAC.
NLL-M	National Lending Library for Science and Technology,
NLL-T	Boston Spa (England).
Note:	References showing an AD number can be purchased at the Clearinghouse for Federal Scientific & Technical Information, U.S. Dept. of Commerce, Springfield, Virginia 22151.

While most of the abstracts were taken entirely or in part from the authors abstracts, others were written by the individuals identified below:

Initial		Initial	
EZS	Evelyn Z. Sinha	ALS	A. L. Smith, Jr.
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SN	Sylvia Nowinska	JPD	J. P. Dickson
RB	Ronald Baker	DLB	Dennis L. Boyer
DBK	Dov B. Krimgold		

Several of the references listed within this bibliography are shown as separate entries but, in reality, can be found as part of the published proceedings of CAT conferences or symposiums. They have been made separate entries because many of the papers presented at the conferences are also available in other publications, possibly easier to obtain than the "Proceedings" which, many times, are afforded very limited distribution. The "National Air Meeting on Clear Air Turbulence" on 23-24 Feb 1966 in Washington, D.C. and the "Symposium on Clear Air Turbulence and its Detection" on 14-16 Aug 1968 in Seattle are two excellent examples of

the above procedure.

Bibliographies - During the reference search to accomplish this listing, the bibliographies entered below were perused and, while the referenced entries were not annotated, both bibliographies were found to be excellent compilations of pertinent CAT material.

Rosenberg, Paul, Beard, M.G., and Harrison, H.T.  
Clear Air Turbulence, Flgt Safety Foundation,  
NASA CR 62028, Dec 1965, 237 p. DAS M(051) V585cr  
Nr 62028. [Contains 274 references.]

Bulford, Dorothy E. Clear Air Turbulence: A  
Bibliography 1950-1967. National Aviation  
Facilities Experimental Center, Atlantic City,  
N.J. Final Rept., Rept. No. NA-68-17, Mar  
1968, 578 refs, 82 p. AD 667731.

The author wishes to thank Mrs. Edna G. Robinson, USAF ETAC for her excellent work in arranging and typing the numerous references in this bibliography.

The valuable assistance obtained from personnel of the various libraries in the Washington, D.C. area is gratefully acknowledged; their efforts facilitated the task of reference searching for this publication.

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(1964 - 1969)

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1964

1. Aplin, Judy E. Atmospheric Turbulence Encountered by Hermes Aircraft on Routes to Africa and the Far East, Royal Aircraft Establishment, Farnborough (England). Tech. Note S 356, May 1964, 34 p. AD 449453.

...Counting accelerometer records were obtained of the turbulence encountered by Hermes aircraft flying mainly on routes from the U.K. - Europe and Africa. Comparison has been made of results from aircraft operated by two airlines, which represent some 427,000 and 495,000 miles, respectively. Typical variations in gust frequency with gust magnitude, altitude, and geographical location were found and the different methods of operating the aircraft also were seen to affect the results. (Author)

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2. American Meteorological Society. Eastern Air-Lines-Weather Bureau Joint Research on CAT. Am. Meteorol. Soc. Vol. 45, No. 5, May 1964, p 290. DAS M(05) A512b.

...Eastern Air Lines weather researchers discovered that clear air turbulence may betray its presence by a change in surrounding air temperatures too slight to register on present cockpit instruments. Eastern has undertaken the development of a special instrument for installation in jet cockpits capable of registering visibly the outside temperatures in fractional degrees that reveal the approach to CAT. The instrument also activates warning lights to alert the pilot when certain "threshold limits" in these temperatures are being reached. Studies of temperature-to-turbulence are underway. The work is being undertaken in cooperation with the U.S. Weather Bureau. (EVS)

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3. Colson, DeVer. Analysis of Special CAT Data Collection Program, February 4-9, 1963. Presented at the 5th Conference on Applied Meteorology, Atlantic City, 2-6 March 1964. Weather Bureau, Washington, D.C. AD 447493.

...This is a study of nonconvective-type turbulence at 18,000 ft MSL or higher over the continental United States. Data were gathered over a 5-day period by commercial and military pilots, and entered on flight cards equally divided into  $2\frac{1}{2}^\circ$  latitude-longitude squares. A complete tabulation by intensity classes, flight-altitude ranges, and 12-hour time intervals for each square was made and placed on punched cards and print-outs. It was found that the probability of turbulence varied considerably across the country, with the greatest probability for both light and moderate occurrences to be over the southeast, the northwest coast, and the northern Rocky Mountains. (Author)

---

4. Endlich, R.M. and Mancuso, R.L. Clear-Air Turbulence and its Analysis by Use of Rawinsonde Data. SRI, Menlo Park, Calif. Cwb-10624. 55 p. Final Report, Jun 1964. AD 603570. DAS M(051) S785fic.

...This investigation of clear air turbulence has several parts. The first section reviews selected aspects of turbulence and emphasizes the large size and persistent nature of certain areas of moderate or severe turbulence. The next section is an investigation of turbulence in pronounced jet-stream flow over mountains. Turbulent layers in these cases appear to have the same mesoscale structure found elsewhere; however, the turbulence appears to be more intense and the areas larger than one would expect with the same flow over level or rolling terrain. Next, a turbulence index (TI) is defined on empirical grounds as the product of wind speed, turning of the wind with height, and change of lapse rate. Several maps are presented that illustrate substantial agreement of computed quantities with the turbulence reports. Standard statistical tests show that both the Ri and TI numbers have definite skill in turbulence analysis, and that combined use of the two numbers is more accurate than use of either one separately. Suggestions are given for further improvement of criteria for analyzing turbulence. Experiments in grid-point analysis of turbulence and in objective turbulence forecasting are recommended. (Author)

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5. Endlich, R.M. and McLean, G.S. Studies of the Climatology of Winds, Temperature, and Turbulence in Jet Streams. SRI, Menlo Park, Calif. Contract AF 19(628)-3304. Final Report, Oct 1964. AD 608773. DAS M(051) S785fist.

...This report consists of three separate papers concerned with the climatology of jet streams and clear air turbulence. The first paper is entitled "Jet-Stream Structure over the Central United States Determined from Aircraft Observations." In this study, empirical models of jet streams are found to agree well with previous models based on data from other regions of the mid-latitudes. Also, we found that variations in the speed field with season and with position in the upper-flow pattern were rather small, so that a single model describes the jet stream adequately.

The second paper is entitled "Empirical Relationships Between Gust Intensity in Clear Air Turbulence and Certain Meteorological Quantities." This paper provides data of a type that have not been available previously, having applications to aircraft and missile design, and to the determination of worldwide turbulence statistics.

The third paper is entitled "Some Autocorrelations and Spectra of Wind and Temperature in Jet Streams." Correlations were computed for paths oriented across jet streams and along jet streams. In all cases, the autocorrelations decreased to zero within 25 to 40 percent of the path length, indicating that the distance considered (length of the data sample) is important in determining the shape of the autocorrelation function. Spectral computations showed that only a small portion of the variance lies in the mesoscale range - i.e., in wavelengths smaller than approximately 200 nm. (Author)

- 
6. Endlich, Roy M. The Mesoscale Structure of some Regions of Clear Air Turbulence. J. Appl. Meteorol. Vol. 3, No. 3, Jun 1964, pp 261-276. 11 refs, 13 figs, cross sections. DAS M(05) J86joa.

...The structure of the atmosphere in regions of clear air turbulence is investigated by means of aircraft observations of wind and temperature in combination with objective and subjective turbulence records. The nature of the aircraft data and the assumptions inherent in the analyses are described. The detailed fields of vertical and horizontal wind shear, stability, and Richardson number are presented for turbulence encountered in three different patterns of flow, viz., a sharp trough, an anticyclonic jet stream, and an intense straight jet. Severe turbulence (equivalent in intensity

## 6. (cont.)

to that measured by the same aircraft in a mature thunderstorm) was found in certain portions of the trough and ridge, and moderate turbulence existed in the straight jet. Comparison of these cases and of twenty other flights indicates certain similarities and certain differences of the flow conditions in the turbulent regions. (Author)

---

7. Houbolt, J.C. et al. Dynamic Response of Airplanes to Atmospheric Turbulence Including Flight Data on Input and Response. NASA TR-R-199, Jun 1964, 115 p. IPB Files.

...A coordinated account of flight measurements of random atmospheric turbulence, of calculated and experimentally-determined airplane transfer functions, and of analytical procedures for determining output responses is given based on power spectral techniques. Implications of these techniques for load prediction and for design are discussed, and a brief review of basic procedures and mathematics involved is also included. (Author)

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8. Jirovskiy, V. Turbulence in Cloudless Air. FTD, Wright-Patterson AFB, Ohio, Report No. TT64 751, Dec 1964, 6 p. Trans. From Letecky Obzor, 7(11) pp 339-340, 1963. AD 455513.

...On May 9, 1963 a Czech TU-104 flew the distance between Djaran and Beirut in a turbulent zone of extreme intensity. Most likely, it encountered turbulence, connected with the greater inclination of the tropopause in the vicinity of the jet stream, which is very dangerous for high-speed aircraft, especially since it also takes place in cloudless space and reaches greater intensities. This report explains the probable causes of turbulence in the case under question and describes the situation. (Author)

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9. Kadlec, P.W. A Study of Flight Conditions Associated with Jet Stream Cirrus, Atmospheric Temperature Change and Wind Shear Turbulence, Eastern Air Lines, Inc., Miami, Fla. Contract Cwb 10674 Final Rpt. 1 Jul 1963-15 Jun 1964. 9 p. AD 447454.

...This study of certain factors that produce atmospheric turbulence and its effect on aircraft in flight has concentrated

## 9. (cont)

on the relationship of jet stream cirrus and temperature change to wind-shear turbulence. Data were collected on 179 flights while riding as a crew member on company, other airlines, and military jet aircraft from July 1, 1963, to June 15, 1964. Detailed horizontal and vertical cross sections for each flight with the corresponding surface and upper-air data were analyzed for this study. Three cloud-pattern models have been developed to associate cirrus formed by jet streams and areas of occurrence of significant turbulence. A fourth model describes those situations where cirrus does not form and the turbulence associated with it. A relationship has been observed between atmospheric temperature changes and the occurrence of wind-shear turbulence. Certain changes of static air temperature at specific rates have produced a short warning period before the encounter of significant turbulence. Development of a turbulence sensor to register these changes has resulted in a test program to acquire more data. The modification of one DC-8 aircraft has been completed to collect improved temperature data on the aircraft flight recorder. (Author)

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10. Kronebach, George W. Automated Procedure for Forecasting Clear-Air Turbulence. (Electronic Computer Branch, Det 51, 1210th Wea Sq, Suitland, Md.) J. Appl. Meteorol., Boston, Vol. 3, No. 2, Apr 1964, pp 119-125, 3 figs, 2 tables, 3 eqs. DAS M(05) J86joa.

...A computer program was written to obtain several parameters which have been useful in identifying clear air turbulence (CAT) from upper-air data. These are vertical and horizontal wind shear, vertical and horizontal gradient of kinetic energy, and Richardson number. In addition, the distribution of CAT with respect to the jet stream and ridges and troughs was investigated. The Richardson number was judged to be the most promising parameter. An automated system was developed which (1) computes the Richardson number for each wind-shear layer for all North American soundings, (2) selects the minimum Richardson number for each sounding, (3) analyzes isopleths of minimum Richardson number, (4) draws these fields with the National Meteorological Center's curve drawer. Areas, outlined by minimum Richardson numbers less than one, are designated as forecast areas and are assumed to persist for twelve hours. Independent data indicate that the forecast areas explain approximately 40% of the reported occurrences of moderate or severe CAT. (Author)

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January 1970

11. Melbourne, University of, Project TOPCAT Meteorological Reports I-VII, Meteorology Department, Australia, May 1964 and Jun 1965, 2 Vols. IPB Files.

...Project TOPCAT, a study of high-altitude clear air turbulence (CAT) over southern Australia, was carried out during August and September 1963 with an instrumented Canberra aircraft operated by a group of the Structures Department, Royal Aircraft Establishment, under the direction of Mrs. Anne Burns, and with the help of a number of Australian organizations. Details of these and the project as a whole were given in the preface to the first set of TOPCAT Meteorological Reports which comprised the following:

- I. A Survey of the Subtropical Jet Stream and Clear Air Turbulence Models K.T. Spillane
- II. Forecasting Aspects of the First Phase of the TOPCAT Trials E.A. Mizon
- III. Clear Air Turbulence Models and Forecasting for Project TOPCAT, Second Phase E.R. Reiter
- IV. Detailed Structure of Two Subtropical Frontal Zones T. Kamiko
- V. A Developing Subtropical Depression and its Frontal Structure T. Kamiko
- VI. A Mesoscale Vortex Model for Synoptic Disturbances Observed During Project TOPCAT R.H. Clarke
- VII. Turbulence and the Detailed Structure of a Subtropical Jet Stream R.H. Clarke

Reports No. IV to VII issued in this volume all have resulted from the work of Mr. R.H. Clarke and his synoptic group of the Division of Meteorological Physics, C.S.I.R.O., who during the first phase of the TOPCAT trials made a thorough study of 5 synoptic disturbances passing over the Woomera area. (UR)

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12. Reiter, Elmar R. Nature and Observation of High-Level Turbulence, Especially in Clear Air, Journal of Aircraft, Vol. 1, No. 2, March-April 1964, pp 94-96, 19 refs, 3 figs. DAS P Col.

...Describes observational evidence of CAT in conjunction with the nature of CAT. Further defines turbulence in both stable and unstable atmospheres. Special attention is given to turbulence problems involving supersonic transport operations and

## 12. (cont)

missile operations. This study is also presented as Colorado State University Technical Paper No. 41, December 1962. DAS M(055) C719at No. 41. (Part Author Abst.)

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13. Reiter, Elmar R. Progress in Clear-Air Turbulence Research and Forecasting. Colorado State University, Fort Collins, Dept. of Atmospheric Science, Jun 29-Jul 2, 1964. AST Paper No. 54, 7 p, refs, eqs. DAS M(055) C719at no. 54.

...A brief description and summary of preliminary findings of Project TOPCAT will be given. This project consisted of clear-air turbulence (CAT) measurement flights executed by a specially-instrumented Canberra aircraft over Southeast and Central Australia. The research program was initiated in order to augment our knowledge on the detailed structure of the upper troposphere and lower stratosphere in view of the requirements for supersonic transport operations. (Author)

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14. Reiter, Elmar R. CAT and SCAT. Astronautics and Aeronautics, N.Y., Vol. 2, No. 5, May 1964, pp 60-65, figs, refs, eqs. DAS P Col.

...Clear air turbulence (CAT) is a small phenomenon which eludes the wide-meshed radiosonde network, the sole tool to investigate the state of the stratosphere. Thus, the obtained data are not sufficient for the safety of commercial supersonic air transport. Cases of CAT associated with vertical vector wind shears frequently found in the region between two merging jet branches, as well as the effects of temperature inversion, are reviewed. Recent research has been improved with the use of sounding balloons, tracked by radar with high accuracy. Refined devices detect vertical wind shears up to 20 kts/50m. Such wind shears are likely to initiate wave formation causing turbulence to flying aircraft. (SN)

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15. Reiter, Elmar R. and Nania, Abele. Jet-Stream Structure and Clear-Air Turbulence (CAT). J. Atmospheric Sci., Boston, Vol. 3, No. 3, Jun 1964, pp 247-260, 13 figs, 11 refs, 2 eqs. DAS M(055) A512J.

## 15. (cont)

...Cloud-photogrammetric studies conducted from the ground reveal the existence of wave perturbations near tropopause level, of a wavelength the same order of magnitude as is experienced in clear air turbulence. A case study of the CAT occurrence on 13 April 1962 reveals the importance of the confluence mechanism of two jet streams and the turning of wind with height in CAT generation. (Author)

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16. Serebreny, S.M. and Wiegman, E. The Distribution of Clear Air Turbulence Reports and Cloud Patterns as Seen in Satellite Photographs, SRI, Menlo Park, Calif., Final Rpt. SRI-4279, Contract CwB 10481, Jan 1964, 51 p. AD 432468.

...Selected COMBAR reports of clear air turbulence for ten days from April and May 1960 are studied in association with the cloud distribution shown by TIROS I during this period. Characteristic cloud patterns accompany certain types of weather systems, particularly low pressure vortices, and often delineate, rather well, the location of jet streams and tropopauses (which are known to be associated with clear air turbulence occurrences), about these weather systems. As a consequence, satellite photographs of low pressure vortices may provide a useful supplemental tool in establishing the areal distribution of clear air turbulence risk during various stages of cyclone development. (Author)

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17. Sorenson, John E. Synoptic Patterns for Clear Air Turbulence. Sponsored by United Air Lines Inc., Chicago, Ill. UAL Meteorology Circular No. 56, 21 Dec 1964. DAS M629.13 U58mc No. 56.

...The effort in this circular is directed toward a greater limitation of CAT forecast areas without omitting areas where the risk of CAT of over light intensity is present. During the study an attempt is made to get closer than heretofore to the cause of the phenomenon.

As a means to this end, all available CAT reports for December 1963 were studied. Reports included those logged by the United Air Lines Weather Center at Chicago, Illinois, and those listed in the U.S. Weather Bureau summary for the month. Of these reports 254 were in the moderate or greater category as reported in the altitude range of 25,000 ft through 41,000 ft. The geographical distribution of these reports is shown in Figure 1. (Author)

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18. Venkiteshwaran, S.P. Observations in India of Turbulence in the Upper Air from Sounding Balloon Ascents, Bangalore, India. National Aeronautical Lab., Technical Note TN-AE-23-64, Mar 1964. 9 p, figs, refs. DAS M(055) 139tn.

...Describes the special features of the F-type radiosonde, in distinguishing from the rotation of the fan whether the downward movement of the radiosonde balloon is due to a strong vertical downward current or due to the accumulation of snow. It shows how the rate of rotation of the fan can be used to identify regions of turbulence in the atmosphere. Observations of turbulence with F-type radiosonde are compared with the inferences drawn by turbasondes in the U.S. and the Dines meteorograph records in India. The regions where turbulence may be observed in India are indicated. The existence of severe turbulence in the upper troposphere and in the stratosphere has been emphasized. (Author)

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19. Wescott, John W. Acoustic Detection of High-Altitude Turbulence, Acoustics and Seismics Lab., Univ. of Michigan, Ann Arbor, Rept. No. 3746 38 T, Mar 1964, 55 p. AD 434705.

...Turbulence is investigated by an acoustical method at altitudes of 55,000 to 73,000 feet. A theory for the power spectrum of noise radiated by turbulence (including clear air) is cited. Descriptions and illustrations of the instruments used to acquire and process the experimental data are presented. (From Author Abst.)

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20. Andrews, W.H. et al. Flight Tests Related to Jet Transport Upset and Turbulent Air Penetration, NASA Conference on Aircraft Operating Problems, "A Compilation of the Papers Presented," Langley Research Center, Langley, Va. May 10-12, 1965, pp 123-136. IPB Files.

...A flight program, utilizing a Convair 880 and a Boeing 720 airplane, was conducted in conjunction with wind-tunnel and simulator programs to study problems related to jet-transport upsets and operation in a turbulent environment. During the handling-qualities portion of the program, the basic static stability of the airplanes was considered to be satisfactory

20. (cont)

and the lateral-directional damping was considered to be marginal without damper augmentation. An evaluation of the longitudinal control system indicated that this system can become marginal in effectiveness in the high Mach number and high dynamic-pressure range of the flight envelope. (Part Author Abst.)

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21. Astheimer, R.W. Infrared Techniques for the Remote Detection of Clear Air Turbulence. Symposium on Remote Sensing of Environment, 3rd, Univ. of Michigan, Ann Arbor, Oct 14-16, 1964, Proceedings, Feb 1965, pp 105-123, 10 figs, 5 refs, eqs. AD 614032.

...It has been established that clear air turbulence is often associated with temperature discontinuities in the atmosphere of the order of 3-5°C. An instrument which could remotely detect such temperature discontinuities at a distance of several miles or more, would be of value as an airborne warning indicator, as well as for general atmospheric studies. Kaplan has suggested a means for determining the vertical temperature profile of the atmosphere from a satellite, by sensing the radiation emitted at several wave lengths within an atmospheric absorption band. The application of this technique to the determination of horizontal temperature distributions within the atmosphere and the detection of clear air turbulence is discussed. (Author)

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22. Bates, F.C. Detection of Generating Eddies in Clear-Air Turbulence Aloft by Acoustical Sensing. Symposium on Remote Sensing of Environment, 3rd, Univ. of Michigan, Ann Arbor, Oct 14-16, 1964, Proceedings, Feb 1965, pp 95-103. AD 614032.

...Proceeding from the findings of many studies of microbarovariations at Saint Louis University and a simple model of eddy generation in clear air turbulence aloft, the hypothesis that generating eddies in such turbulence cause the microbarovariations is offered. Estimates of amplitude and frequency based upon the model and typical values for a turbulent layer at 10 km are made and found to compare favorably with those sensed by the Macelwane microbarovariograph. Potential application of the consequent acoustical remote-sensing technique in the detection, mapping, tracking and prognosis of CAT aloft is outlined. Testing of the hypothesis and development of improved and field instruments remain to be accomplished. (Author)

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23. Binding, A.A. Association of Clear Air Turbulence with 300-mb Contour Patterns. Met. Mag., London 94(1110):11-19, Jan 1965. 12 figs, table, 6 refs. DAS M(05) G786m.

...Experience at London Airport has indicated a possible connection between clear air turbulence and the curvature of the flow. The investigation reported here was made to determine to what extent 300-mb contour patterns might be associated with CAT and whether such associations could be of use in forecasting. Several cases of CAT were found to be in positions remote from jet-stream core. The non-jet stream cases were associated with identifiable 300-mb contour patterns and it was found possible, in the year under review, to associate jet-stream cases as well with 300-mb patterns, thus indicating the possibility of forecasting CAT primarily from one prontour chart alone. The data used were taken from a record maintained at London Airport of reports of CAT from aircraft on transatlantic routes. Three conditions for turbulence are given: 1) ridge type, where contours are anticyclonically-curved and the wind speeds and curvatures near to the theoretically limiting values; 2) sharp trough type, which would, on passage, produce a wind shift of at least 90°, and 3) instability area type, with marked cyclonic curvature of the contours and cyclonic shear with the probability of cumulonimbus activity below. (Author & RB)

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24. Burns, Anne and Rider, C.K. Power Spectral Measurements of Clear Air Turbulence Associated with Jet Streams, Project TOPCAT, TR 65210, Royal Aircraft Establishment, Farnborough, England, Sep 1965, 39 p. AD 476548.

...Preliminary information is presented on the power spectral data obtained during Project TOPCAT in Australia. Measurements of moderately-severe clear air turbulence were obtained from a Canberra aircraft flying at altitudes of 26000 to 33000 ft in the vicinity of the sub-tropical jet stream. In some respects, particularly at long wavelengths, the spectra are dissimilar to those found for low-level turbulence and there are indications that the turbulence is anisotropic. At short wavelengths the power spectra agree well with a minus 5/3rd power law, and the energy densities of the three components of the velocity of turbulence are similar. (Author)

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25. Collis, Ronald T.H. Use of Lidar in Atmospheric Research, SRI, Menlo Park, Calif., American Institute of Aeronautics and Astronautics, AIAA Paper No. 65-464, 1965, 3 p, figs, refs. DAS M(055) A5121p.

...Describes the basic form of the lidar (light detection and ranging) technique; discusses and illustrates its capabilities and limitations as an atmospheric probe; and examines how it can be applied to research into a variety of atmospheric phenomena. Possible future developments are indicated. It is concluded that lidar is a tool of great promise for atmospheric research, providing new capabilities for observing clouds and the state of the "clear" atmosphere. (DBK)

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26. Colson, D. and Panofsky, H.A. An Index of Clear Air Turbulence, Dept. of Met., Penn State Univ, Quart. J. Roy. Meteorol. Soc. Vol. 91, No. 390, Oct 1965, pp 507-513. DAS M(055) R888q.

...An index is derived for the intensity of turbulence in a sloping baroclinic layer. Preliminary estimates of this index from ordinary meteorological information suggest that the index is proportional to turbulent energy and that it discriminates better between regions of varying intensity than vertical wind shear or Richardson number. An exact test, however, would require more detailed synoptic information than is usually available. (Author)

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27. Crooks, W.M. High Altitude Clear Air Turbulence, Lockheed-California Co., Burbank, Interim Report, Apr 1963-Fet 1965, LR 18794, TR 65-144, Sep 1965. AD 474616.

...The purpose of this report is to describe the high altitude clear air turbulence (HICAT) program. In the work accomplished thus far, an analog FM instrumentation system utilizing a fixed-vane gust probe and a 7-hour recording system was installed aboard an Air Force U-2. HICAT searches were conducted at Air Force bases in California, Florida, and Puerto Rico. Over seven hours of HICAT associated with jet streams, convective activity due to low level heating, and mountain wave activity were recorded. (Part Author Abst.)

28. Endlich, R.M. and Mancuso, R.L. On the Analysis of Clear Air Turbulence by Use of Rawinsonde Data. Monthly Weather Rev. Wash., D.C., Vol 93, No. 1, Jan 1965, pp 47-58, 9 figs, 2 tables, 14 refs. DAS M(05) U587m.

...Regions of clear air turbulence in the upper troposphere and lower stratosphere are classified into 4 groups and the characteristics of each group are summarized. An empirical turbulence index is defined that describes meteorological conditions associated with a type of turbulent region that is relatively large and that sometime contains severe turbulence. The turbulence index, Richardson's number, and other meteorological quantities are described in relation to a clearly-defined case of turbulence observed by a research aircraft. (Part Author Abst.)

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29. Endlich, R.M. and McLean, G.S. Empirical Relationships between Gust Intensity in Clear Air Turbulence and Certain Meteorological Quantities. J. Appl. Meteorol. Vol. 12, No. 4, Apr 1965. pp 222-227. DAS M(05) J86joa. (See Stanford Research Institute, Final Rpt. Oct 1964. DAS M(051) S785f1, AFCRL 65-635, Aug 1965, AD 623941).

See Item #5 (1964) Paper #2.

...Due to a lack of observational data, little information exists in the literature concerning quantitative relationships between turbulent gust intensity in the free atmosphere and commonly measured meteorological quantities. Measurements of turbulence, wind, and temperature made by a B-47 research aircraft are used to investigate such relationships in order to satisfy several practical needs. It is found that a quantity that is the product of wind speed and turning of the wind with height is more closely related to turbulent gust intensity than vertical wind shear or Richardson's number. Variations in the frequency of occurrence of turbulence are determined as the quantities mentioned above increase in magnitude. (Author)

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30. Endlich, R.M. Objective Analysis and Forecasting of Clear Air Turbulence. SRI, Menlo Park, Calif. Final Report, Jun 1965. Contr. Cwb-10871. DAS M(051) S785f10.

...This investigation is based on pilot reports of high-level turbulence for the special turbulence reporting period of February 4 to 9, 1963 and upon standard meteorological data

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30. (cont)

analyzed by computer. During this five-day period, a series of rather sharp upper-air troughs travelled across the United States, while jet streams were notably absent. Many of the regions reported as turbulent were associated in a general way with the troughs. In order to test and compare meteorological quantities as indicators of turbulence, a number of vertical derivatives of wind and temperature were computed from individual soundings. We found that the vertical wind-shear vector was as good a single criterion as any; however, several other quantities (including Richardson's number and wind-direction shear) were nearly as effective. (Author)

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31. Finkelstein, Roy P. A Parametric Analysis of Automatic Low-Altitude Flight. Operational Evaluation Dept., Stanford Research Inst. Menlo Park, Calif. Contract DA-49-092-ARO-10, Oct 1965. 31 p. AD 488219L.

...A parametric analysis was performed to determine the family of minimum altitudes at which an aircraft can fly above the terrain while maintaining a fixed level of safety. These altitudes will be used to establish constraints on the Soviet low-altitude threat for use in Army Air Defense Studies. The aircraft is assumed to be under the control of an automatic terrain-avoidance system that programs maneuvers in the vertical plane. Computer programs were written to generate terrain with the desired characteristics and to simulate the flight of an aircraft over the terrain. Included in these models are the effects of air turbulence, system errors, and reaction times, the probability of aircraft survival (i.e., no collisions) for 100 km of flight, its median clearance above the terrain, and its average control load. All were obtained as functions of the type of terrain, air turbulence, aircraft speed, desired clearance, and control-system characteristics. Included as part of control-system characteristics were control equations, system errors and delays, sensor range, and range bias. From the data, the minimum obtainable median altitudes for various safety levels were plotted against aircraft speed, type of terrain, and wind conditions. (Author)

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32. Franken, P.A. et al. Airborne Investigations of Clear Air Turbulence with Optical Radar. Michigan Univ., Ann Arbor. Contract DA-49-092-ARO-10, Dec 1965. 175 p. AD 635030.

## 32. (cont)

...The program was initiated to explore the possibility that characteristic optical radar echoes might actually be correlated with clear air turbulence. A light, twin engine airplane was equipped with a laser radar and ancillary equipment for monitoring acceleration, temperature variations, and relevant meteorological data. The design of this equipment and the development of the flight programs were predicated on theoretical considerations of optical scattering from particulate matter. (Author)

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33. Hardy, Kenneth R. et al. Multiwavelength Backscatter from the Clear Atmosphere. Air Force Cambridge Research Labs., L.G. Hanscom Field, Mass. Rept. No. AFCRL-ERP-191, AFCRL-66-308. Dec 1965. 20 p. AD 635317.

...Simultaneous experiments have been conducted with ultra-sensitive radars at 3.2-, 10.7-, and 71.5-cm wavelengths to observe 'angel' echoes from apparently clear air and to diagnose the scattering mechanism. Two types of echo layers have been found. Type I echo layers appear incoherent at long ranges or with wide beams but are seen to be composed of discrete coherent echoes when viewed with high resolution. Type II echo layers are composed of incoherent echoes at all ranges, show little or no wavelength dependence, and are generally undetectable at 3 cm. (Part Author Abst.)

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34. Harrison, Henry T. The Mountain Wave. U.S. National Aeronautics & Space Administration, Wash., D.C. NSR 33-026-001, NASA CR-315, Oct 1965. 56 p, incls., figs. DAS M(051) v585cr Nr 315.

...Five case histories of severe to extreme Clear Air Turbulence (CAT) are analyzed. All are mountain wave situations. The study is intended for alleviation of problems posed by CAT. The detection and a possible forecast of CAT are discussed. Incidents of CAT penetration of drastic nature, as well as its effect on airline operation, are reported and each case is illustrated by a chart of air circulation. Individual case histories of airline incidents provide evidence that the tropopause zone is a favored one for turbulence. (SN)

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35. Kadlec, F.W. Flight Data Analysis of the Relationship between Atmospheric Temperature Change and Clear Air Turbulence, EAL, Inc. Dept. of Meteor., Miami, Fla. Prepared for USWB, Contract No. Cwb 10888, Jun 1965, 49 p. AD 620989.

...Certain atmospheric temperature changes have been observed to be a factor in detecting the occurrence of clear air turbulence, especially at jet altitudes above 25,000 ft. Data for this study were collected on 146 flights during the year while riding as an extra crew member in the cockpit of airline and military jet aircraft. An aircraft flight data recorder which was modified to collect static air temperature information, provided another valuable source of research data. The study concentrated on investigating the validity of the theory that temperature gradients may be used to indicate clear air turbulence. (Part Author's Abst.)

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36. McConathy, D.R., Jr. A Detailed Analysis of Clear-Air Turbulence over Utah on April 10-11, 1963. Penn State Univ., Mineral Industries Experiment Station, University Park, Pa. Scientific Report No. 1. Contract No. Cwb-10393. Jan 1965, 32 p, 2 tables, 16 figs. DAS M(051) P415sc no. 1.

...Previous studies have related areas of Clear Air Turbulence to regions of sloping baroclinic or adiabatic layers with low Richardson numbers. With the aid of detailed aircraft measurements and radiosonde soundings, an analysis of a strongly baroclinic region is made. Although some of the usual problems of uncertainty in data and analysis arise, the results agree well with previous theory. In one region of intense thermal gradient the agreement between geostrophic and actual wind fields is poor, thereby excluding the use of the thermal wind equation in obtaining realistic information. Values of the Richardson number and ICE index are analyzed over a cross-section grid with the aid of a computer, and the results show low values of Ri and high values of ICE in regions of turbulence. The observations are consistent with the hypothesis that the critical Richardson number lies within the range 0.25-0.50, although they are not sufficient in density or accuracy to establish this range definitely. (Author)

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37. McLean, G.S. An Investigation into the Use of Temperature Gradients as an In-Flight Warning of Impending Clear Air Turbulence. Air Force Cambridge Research Labs., L.G. Hanscom Field, Mass. Feb 1965, 30 p. Rept. No. ERP-85, AFCRL-65-117. AD 61360.

## 37. (cont)

...This paper discusses a study that was undertaken to investigate the technique of using in-flight temperature gradients to forecast impending Clear Air Turbulence and some recent studies concerning the relationship between jet-stream winds and turbulence. (Author)

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38. Merritt, E.A. and Wexler, R. Radiometric Detection of Clear Air Turbulence. Paper presented at Fifth Conference on Applied Meteorology of the American Meteorological Society, Mar 1964. Aracon Geophysics Co., Concord, Mass., Oct 14-16, 1964, Symposium on Remote Sensing of Environment, 3rd, Univ. Michigan, Ann Arbor, Oct 14-16, 1964. Proceedings, Feb 1965, pp 125-140. AD 614032.

...The mesoscale nature of Clear Air Turbulence (CAT) makes it unlikely that any technique developed from synoptic scale observations will prove generally effective to predict the occurrence of significant turbulent areas in the upper troposphere. An airborne passive-detecting system is, therefore, required.

CAT often occurs in regions of strong horizontal and vertical wind shears which are associated with strong horizontal temperature gradients; the detection of these temperature gradients and turbulence-related temperature microstructure might provide the means to sense the turbulent area. (Author)

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39. Nanevich, Joseph E. et al. Correlation between Clear Air Turbulence and Aircraft Electrical Activity. Stanford Research Inst., Menlo Park, Calif. Final Rept., Oct 63-Aug 65, Oct 1965, 76 p. AD 625309.

...The results of a cooperative effort by Stanford Research Institute, United Air Lines, and Air Force Cambridge Research Laboratories to determine the correlation between regions of Clear Air Turbulence (CAT) and aircraft electrical activity are described. Corona discharges from precipitation static dischargers on DC-3 aircraft were monitored and correlated with CAT encounters. A significant correlation was found to exist between CAT encounters and periods of electrical discharge. It is suggested that these electrical discharges may be caused by electric fields in the region of Clear Air Turbulence,

## 39. (cont)

particulate matter in the region that charges the aircraft, or a combination of both. A meteorological analysis was made of the regions where turbulence associated with electrical activity was observed. This analysis indicated that the CAT incidents were associated with jet streams. (Author)

See also: National Air Meeting on Clear Air Turbulence, Wash., D.C. Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 77-83; p 96, figs, table, refs. DAS M51.5 N277pro.

See also: Correlation between Clear-Air Turbulence and Electric Fields. Stanford Research Inst., Menlo Park, Calif. Rpt. No. SR-1, Feb 1965, 33 p. AD 613035.

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40. Pinus, N.Z. (Editor). Atmospheric Turbulence, Translation of "Atmosfer'naya turbulentnost," Trudy Tsentral'noy Aerol. Obser. No. 54, Gidromet. Izdat., Moscow 1964, NASA Tech Translation, TTF-246, Wash., D.C. Sep 1965, 129 p. IPB Files.

...This collection is concerned with the work conducted at the Atmospheric Dynamics Laboratory, Central Aerological Observatory, 1961-1962.

Some Results of the Experimental Investigations of the Atmospheric Turbulence Using Radiosondes, V.P. Belyayev et al.

The Turbulence in Jetstreams in the Clear Sky, A.A. Reshchikova

Application of the Boundary Layer Method to the Determination of the Parameters of Turbulence in the Free Atmosphere, V.A. Shnaydman

Turbulence in the Proximity of Jetstreams, T.P. Krupchatnikova

Some Results of the Determination of Turbulence Characteristics in Jetstreams, V.D. Litvinova

Application of a Thermoanemometer on an Aircraft, N.K. Vinnichenko

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41. Reiter, Elmar R. and Burns, A. Atmospheric Structure and Clear Air Turbulence. Colo. State Univ. Atmospheric Sci. Tech. Paper No. 65. Presented at the Intern Colloq. on Fine-scale structure of the Atmosphere, Moscow, 15-22, Jun 1965, 17 p, refs. DAS M(055) C719at No. 65.
- ...Measurements of Clear Air Turbulence spectra conducted by a Canberra aircraft over Australia between August and October 1963 reveal the existence of a wavelength region from approximately 2000 to 4000 ft in which the atmosphere receives turbulent energy mainly in the w-component of motion. It is suggested that this energy stems from gravitational shearing waves which break up into turbulent eddies below critical wavelength. The energies of these turbulent eddies seem to be well represented by a proportionality to  $w^{\frac{2}{3}}$ , characteristic of the inertial subrange of turbulence. (Author)
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42. Rosenberg, Paul, Beard, M.G., and Harrison, H.T. Clear Air Turbulence, Flight Safety Foundation, NASA CR 62028, Dec 1965, 237 p. DAS M(051) U585cr Nr 62028.
- ...This report was prepared to assist NASA in keeping abreast of research and development projects directed toward the alleviation of problems posed by flight in clear air turbulence (CAT). Included are a poll of industry for information about development activities on CAT detection, a chronological listing of conferences and interviews, reports on conferences and interviews, airborne CAT detection devices in active flight testing. CAT incidents, meteorological developments relative to CAT, and economic aspects of turbulence in airline operations. A bibliography of 274 references is also included which contains references to the physical, meteorological, and operational aspects of air turbulence. (Part Author Abst.)
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43. Spillane, K.T. Atmospheric Structures Associated with Turbulence in the Free Atmosphere. Australian Meteorological Magazine, Melbourne, No. 50:44-45, Sep 1965, refs, eqn. DAS M(05) A938.
- ...Reports briefly on the results of a study where the telemetered information from 54 pilotless aircraft flights, made over a period of several years at altitudes from 15,000 thru 65,000 ft, was interpreted in terms of turbulence by way of the "roll-rate" record of the aircraft, and related to vertical wind shear, Richardson number, and to the statistic stability as well

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as to its local and individual changes. Turbulence was concentrated around 35,000 ft with another and more pronounced maximum around 55,000 ft (the latter recently confirmed by U-2 flights), believed to arise from mesoscale disturbances whose vertical and horizontal distances are of the order of 3000 ft and some hundreds of miles, respectively. (Author)

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44. Stanton, T.E. Convective Clear Air Turbulence, Hqs Third Wea Wg, Offutt AFB, Nebr. Scientific Services Tech. Note 11, May 1965, 33 p, 13 figs, 16 refs. IPB Files.

...Convective CAT can be defined as that turbulence in the upper troposphere caused by shallow convection. It may occur in clear air but is more frequently associated with a cirrus cloud shield. It does not include turbulence associated with cumulonimbus or towering cumulus. However, since instability rather than shearing stresses provide the primary energy source, the techniques utilized to forecast thunderstorms are applicable. The primary region for the occurrence of convective CAT is in the barotropic zones on the anticyclonic side of the jet stream, particularly in areas of thick overcast cirrus. (Author)

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45. United States Air Force, Dept of. Clear Air Turbulence Meeting, 26-27 Apr 1965, Washington, D.C., 283 p. AD 668080.

...Clear Air Turbulence is recognized as one of the unsolved problems in aviation meteorology. While the intensity of this high level or wind shear turbulence is not as severe as thunderstorm turbulence, it can result in injuries to passengers and crew, possible loss of control of the aircraft, and in some extreme cases some actual damage to the aircraft. The high level turbulence encounters are all the more dangerous because they usually occur without any visual warning. Work on this problem can be divided into four main categories: data collection and analysis, theoretical studies, development of forecast techniques, and detection or warning devices. (Author)

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46. Wescott, John W. Acoustic Detection of High Altitude Turbulence, published in Proceedings 1964 AFCRL Scientific Balloon Symposium A.F.S.G. No. 167, AFCRL 65-486, Jul 1965, pp 295-316, 19 figs. AD 619695.

...The causes of low-frequency acoustic background noise that was monitored from instrumented balloons floating at about 60,000 feet were investigated. Tape-recorded samples of the noise were analyzed. Spectrograms, signatures, cross-correlations, and probability-density curves were obtained. Examples are shown. The results indicate that Clear Air Turbulence is one of the principal sources of infrasound in the upper air. A theory for the power spectrum of the far-field noise radiated from the turbulence is cited, and the predicted spectrum is compared to experimental results. (Author)

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47. Wiegman, Eldon J. The Distribution of Clear Air Turbulence Reports and Cloud Patterns as seen in Satellite Photographs. Stanford Research Institute, Menlo Park, Calif. Final Report, SRI project 4842. Contract Cwb-10791. Jan 1965. 101 p. DAS M(051) S785fidis.

...The objective of the study was to ascertain if the cloud patterns displayed in satellite photographs would provide an aid in locating areas of Clear-Air-Turbulence risk. The data period consisted of four days in April and two days in May 1963. A total of 1,042 reports (including turbulence and no-turbulence) taken between the time span beginning 3 hours prior to the earliest orbit and ending 3 hours after the latest orbit on each day were available over the U.S. for the six-day period. These reports include both military and civilian aircraft operating between 7,000 and 42,000 feet MSL. (Author)

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48. Atlas, David et al. Optimizing the Radar Detection of Clear Air Turbulence, USAF, Cambridge Res. Labs., L.G. Hanscom Field, Mass. Report No. AFCRL ERP 248, AFCRL-66-354, Apr 1966, 15 p. AD 648723.

48. (cont.)

...A general analysis is made of the turbulent refractivity spectrum in and beyond the limiting microscale and a relation derived for its scattering reflectivity in either the back or bistatic directions. Radar reflectivity is computed as a function of wavelength for regions of CAT. The results are compared to the minimum detectable reflectivity of airborne radars having optimum state-of-the-art characteristics at each wavelength. It is shown that the best radars now feasible can barely detect the most reflective CAT at 10 n mi (i.e., 1 minute warning). A 20-db improvement in sensitivity is required for detection of most CAT, which appears to be just attainable by pre-detection integration. The optimum wavelength to implement is 5-6 cm. The best radar at this wavelength will also detect cirrus clouds reliably. Whether detecting clouds or chaff, a measure of the echo fluctuation (or Doppler) spectrum is required to identify the intensity of CAT. However, in the case of high altitude clear air echoes, there is an indication that the reflectivity in excess of some minimum threshold value is a sign of some degree of mechanical turbulence. It is also demonstrated that a ground-based forward-scatter link holds great promise for reliable CAT detection. A tentative quantitative classification of CAT severity is also proposed. (Author)

See also: Optimizing the Radar Detection of Clear Air Turbulence, J. of Applied Meteo., Vol. 5, No. 4, pp 450-460, Aug 1966, figs, table, refs, eqs.

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49. Beard, M.G. Analysis of Clear Air Turbulence Incidents. (In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 136-139, table.) DAS M51.5N277 pro.

...Analysis of turbulence incidents since 1959 indicates that the record could have been much better if a good CAT detector had been available. A device which defines CAT areas and indicates the degree of turbulence could be more exact than weather radar is in indicating storm areas. This paper briefly summarizes the turbulence incidents during the last 6 years and discusses the cause of some of the more severe ones. (Author)

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50. Beard, M.G. Status Report on Latest Development in Clear Air Turbulence, Journal of Aircraft, Vol. 3, No. 5, Sep-Oct 1966. pp 443-448, fig. DAS P Col.

...This is a service to the governmental departments interested in this field and to industry. This paper is a status report about new developments in CAT forecasting; it also is a résumé of the various proposed principles of CAT detection and the detection devices being developed and laboratory and flight tested. (Author)

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51. Beckwith, W. Boynton. Minimizing the Effects of Mountain Waves and Shear Generated Clear Air Turbulence in Airline Operations. (In: National Air Meeting on Clear Air Turbulence, Wash., D.C. Feb 23-24, 1966, Proceedings, N.Y. Society of Automotive Engineers, 1966, pp 181-185, figs, refs.) DAS M51.5 N277pro.

...The development of techniques employed by the airlines in overcoming the problem of Clear Air Turbulence is outlined. Improvement in transport aircraft brought new sets of challenges in this area which were overcome by applied meteorological studies conducted by the airlines and assisted by military and government research. A distinction is made in the methods of bypassing the turbulence regions caused by wind shear and those caused by the mountain wave. A new study on mountain-wave turbulence evasion showing considerable promise is discussed. Recommendations are made on methods of keeping pace with an increasing exposure to this important operational problem. (Author)

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52. Bontrond, E.A. (Comment on) De Ver Colson: Summary of High Level Turbulence over the United States. La Météorologie, Paris, Ser. 4, No. 74:135-140, Apr/Jun 1964, issued 1966. Figs, tables. French, English and Spanish summaries p 135. DAS M(05) M589v.

**In French**

...Atmospheric turbulence is a phenomenon of great complexity, depending on many variables, and not permitting further systematic and continuous observations. So, a statistical way is researched in order to enable this study, as for example in France, Météorologie Nationale Monographies, No. 17, of Berenger and Heissat, or in the survey of De Ver Colson, Monthly Weather Rev. 91:10-12, 1963. It is the results of this latest work which are analyzed and commented on here. The

## 52. (cont)

author is making every endeavor to estimate the risks of turbulence in terms of the period of the year, geographic situation, height, position relative to jet streams, and type of synoptic situation. Particular attention is paid to the observations made in the stratosphere which unfortunately are few in number. (Author)

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53. Bray, R.S. and W.E. Larsen. Simulator Investigations of the Problems of Flying a Swept-Wing Transport Aircraft in Heavy Turbulence, NASA Conference on Aircraft Operating Problems, "A Compilation of the Papers Presented," Langley Research Center, Langley, Va. May 10-12, 1965, pp 137-148. IPB Files.

...An investigation of several factors which may contribute to the problem of piloting jet transport aircraft in heavy turbulence was conducted by using a piloted simulator that included the most significant airplane response and cockpit vibrations induced by rough air. Results indicated that the primary fuselage structural frequency contributed significantly to a distracting cockpit environment, and there was obtained evidence of severely reduced instrument flight proficiency during simulated maneuvering flight in heavy turbulence. It is concluded that the addition of similar rough-air response capabilities to training simulators would be of value in pilot indoctrination in turbulent-flight procedures. (Author)

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54. Breese, R.C., Fried, D.L. and Seidman, J.B. Remote Measurement of Differential Atmospheric Velocity. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 135-162, figs, refs, eqs. DAS M51.5 W277pro.

...A concept for detection of Clear Air Turbulence utilizing the Doppler frequency shift in laser light backscattered from atmospheric aerosol is described. The concept employs detection of beat frequencies in the output current of a photo-detector resulting from photo mixing the backscattered light from 2 laser pulses illuminating separated volumes of air. Analysis of the spectral and coherence properties of scattered light is given which proves that the basic phenomena exist. The realizability of a practical system depends upon sufficient aerosol densities and higher performance lasers to achieve adequate S/N at useful distances. (Author)

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55. Breece, R.C. et al. Design Study of Laser Radar for Detection of Clear Air Turbulence. Space & Information Systems, Div. North American Aviation, Inc., Downey, Calif. Rept No. SID-66-450, Jun 1966, 170 p. Contract AF 19(628)-5135. AD 634886.

...The objective of the research was to perform a design study and feasibility demonstration of a Doppler laser/radar system for use in detection of Clear Air Turbulence. Both CW and pulsed radar techniques were investigated to determine applicability to analysis of laser light backscattered from atmospheric molecules and aerosol particles in order to measure macroscopic motion of the air. It was desired to detect wind gusts in excess of 25 feet per second while operating in a jet aircraft at an altitude of approximately 30,000 feet. (Author)

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56. Brylev, G.B. et al. Joint Radar and Aerological Observations in the Lower 1.5 Km of the Atmosphere. Rept. No. T-R-523, Mar 1966, Contract No. AF 19(628)-3880, 26 p. AD 631967.

...The results of joint radar and aerological observations in the lower 1.5 km of the atmosphere are discussed, and a connection is indicated between radar echoes from a clear sky and convective and turbulent motions in the atmosphere. (Author)

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57. Buehler, W.E. and Lunden, C.D. Radar Detection of Turbulence in the Upper Troposphere. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 107-118, figs, refs. DAS M51.5 N277pro.

...Encounters of jet aircraft with high altitude turbulence prompted the investigation of various techniques to probe and locate turbulence in areas lacking particles (rain drops, hail stones). A promising technique is to measure the radio refractive eddies and gradients by radar backscatter. Radio refractive index eddies can, in principle, be found where the atmosphere characterized by a nonadiabatic lapse rate of refractive index is stirred up by turbulence. This paper presents a sequence of VHF backscatter experiments which will hopefully lead up to an airborne CAT detector. Described are: A CW bistatic backscatter experiment showing returns from turbulent volumes, a monostatic pulsed radar with returns from definite turbulent cells at various altitudes, and an airborne experiment carried aboard a jetliner. The wavelength

57. (cont)

dependence of radar backscatter on the detectability of significant turbulent eddies is discussed. (Author)

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58. Burns, Anne et al. Turbulence in Clear Air Near Thunderstorms. U.S. ESSA, NSSL Tech Memo IERTM-NSSL-30, Dec 1966. 20 p, figs, tables, refs. Contents: Burnham, J. and Spavins, Clifford S. Some Results of a Study of Atmospheric Turbulence in Clear Air above Thunderstorms and of the Relationship to Weather Radar Pictures, pp 1-9. Burns, Anne and Harold, Terence W., Atmospheric Disturbance Encountered by A Canberra over Storms at Oklahoma on May 27, 1965, pp 10-19. DAS M(055) v5852re No. 30.

...In the first article, derived gust velocities up to 20 ft/sec and indicated airspeed fluctuations up to 34 ft/sec have been measured during flight through clear air at altitudes between 40,000 ft and 45,000 ft in thunderstorm areas. The possible use of weather radar to avoid such disturbances is discussed. The second article notes that in clear air over the top of a group of storms, a Canberra aircraft encountered rapid changes in temperature and horizontal airflow and moderate to severe turbulence. An explanation involving the deflection of the wind over the storm tops may account for the aircraft observations. The disturbance is discussed as a potential cause of aircraft upsets. (Author)

See also: Burnham, J. and Spavins, C.S. Some Results of a Study of Atmospheric Turbulence in Clear Air above Thunderstorms and of its Relationship to Weather Radar Pictures. Logistics Div. General Staff, Wash. D.C. Rept. No. TM-AERO-928, Mar 1966, 15 p. AD 487330.

See also: Burns, Anne and Harold, T.W. An Atmospheric Disturbance Encountered by a Canberra Aircraft over Storms at Oklahoma on 27th May, 1965. Royal Aircraft Establishment Farnborough (England). Rept. No. TR-80241, Aug 1966, 19 p. AD 805672.

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59. Clark, John B. Pilot Technique in Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 190-197, figs, refs. DAS M51.5 W277pro.

...Clear Air Turbulence and thunderstorm turbulence are compared. The flight technique to be used is the same in all turbulence. Upsets in thunderstorm turbulence are discussed. Years ago there was evidence of clear pattern in the upsets involving propeller-driven airplanes. There was heavy airplane nose-down elevator use following a violent updraft with eventual recovery from a deep dive. A similar pitch axis pattern is apparent in jet upsets. The swept-wing jet has different stability characteristics; has a motor-driven horizontal stabilizer as well as an elevator to control around the pitch axis; and has improved flight instrumentation. Pilot training and a stabilizer modification have contributed to a dramatic decline in incident reports. (Author)

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60. Clarke, R.H. Turbulence and the Detailed Structure of a Sub-tropical Jet Stream. J. Atmospheric Sci., Vol. 23, No. 5, Sep 1966, pp 516-530, 27 refs, 3 appxs, 14 figs, formulae, map. DAS M(05) A512j.

...Jet-stream wind data obtained during Project TOPCAT in August 1963 at Woomera, when rid of fortuitous detail by averaging serial soundings (about 12 at hourly intervals), show detail in the cross-axis flow which can be ascribed with fair certainty to sub-synoptic scale eddy viscosity. This fact is employed to estimate stress, eddy viscosity, and viscous dissipation over one mean profile taken in the jet axis. These are found to have values compatible with existing knowledge, and, with eddy stress in the strong shears beneath a jet stream of order  $1 \text{ dyne/cm}^2$ , one can explain at least a high proportion of the upper branch of Krishnamurti's mean cross-axis flow. The variation of vertical velocity with height is qualitatively that inferred from Angell's and Krishnamurti's observations. (Part Author Abst.)

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61. Colson, DeVer. Analysis of Clear Air Turbulence During Selected 5-Day Data Periods. Weather Bureau, Silver Spring, Md., Techniques Development Lab. Final Rept., Dec 1966, 77 p. AD 648610.

## 61. (cont)

...Clear Air Turbulence data were collected from two of the four worldwide reporting periods set up by the International Civil Aviation Organization (ICAO). The occurrences and non-occurrences of turbulence were summarized with respect to time periods, altitudes, and geographical locations. These data were analyzed in relation to associated meteorological parameters and large-scale synoptic patterns. Special attention was given to areas with at least 25 percent probability of moderate or greater turbulence. Vertical wind shear appeared to be an important parameter along with 12-hour changes in wind speed, vertical wind shear, and horizontal wind shear. The synoptic patterns on the mean 300-mb charts and the individual 300-mb charts were discussed in relation to the probabilities of moderate or greater turbulence. The following forecast criteria were suggested: moderate or greater turbulence will be found (1) within 150 miles of a jet stream with at least a 100-knot maximum wind speed if the vertical wind shear is at least 4 knots per 1000 feet, or (2) within 150 miles of a sharp trough line with a marked horizontal wind shear across the trough line. (Author)

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62. Colson, DeVer. Nature and Intensity of Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y., Society of Automotive Engineers, 1966. pp 1-4; 27. Tables, refs. DAS M51.5 N277pro.

...The phenomenon of CAT is reviewed indicating the role of wind shear, gravity waves, Richardson number, and other indices in relation to turbulence intensity. Standard CAT intensity criteria are reviewed, including vertical accelerations, derived gust velocities, and airspeed fluctuation. Various descriptive criteria are reviewed along with some newer concepts such as "chop". A panel has been established to up-date the current intensity criteria. A research flight program is now underway which will furnish a more complete understanding of CAT and a basis for a more quantitative set of intensity criteria. (Author)

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63. Conner, Fox. Preliminary Design Study for a HI-HICAT Vehicle and Instrumentation System. Lockheed-California Co., Burbank. Final Rept. 1 Jun-31 Dec 65, Oct 66, 144 p. AD 809829.

## 63. (cont)

...A preliminary design study was conducted on an unmanned HI-HICAT (high-high altitude critical atmospheric turbulence) vehicle and instrumentation system to measure turbulence at altitudes from 70,000 to 200,000 feet. The vehicle configuration selected as optimum for this extreme range of altitudes is a parawing. For the study, emphasis was placed on designing a system for the middle portion of the altitude band from 100,000 to 150,000 feet. In this band a lifting body configuration is competitive with the parawing. Both systems feature a one-stage vehicle which is air-launched from an F-4C aircraft at supersonic speeds. Turbulence data is gathered by a digital system and stored on a magnetic tape recorder and telemetered back to the launch site. (Author)

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64. Crooks, W.M., Hildreth, W.W. and Stauffer, W.A. Clear Air Turbulence. Lockheed Horizons, Burbank, Calif. No. 5 2nd quarter 1966. pp 78-96. IPB Files.

...The phenomenon of Clear Air Turbulence and details of the HICAT program carried out by the United States Air Force and Lockheed Aircraft are discussed. Methods for the satisfactory measurement of the data and HICAT encounters, are given. The nature of turbulence, gust design procedures, models of turbulence, and response characteristics of the Lockheed L-2000 aircraft are discussed. (ALS)

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65. Endlich, Roy M., Serebreny, Sidney M. and Ligda, Myron, G.H. Clear Air Turbulence Research Programs of the Aerophysics Laboratory. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 69-76, figs, refs. DAS M51.5 N277pro.

...Research programs are discussed that concern the nature and causes of Clear Air Turbulence; the practical identification of turbulent regions by computer analysis of ordinary radiosonde measurements of winds, temperature, and pressure; the use of satellite photographs of clouds in turbulence analysis; determination of the climatology of Clear Air Turbulence; and possible detection of layers that contain turbulence by means of lidar observations. (Author)

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66. Endlich, R.M. et al. Techniques for Determining a World-Wide Climatology of Turbulence through Use of Meteorological Data. Stanford Research Inst. Menlo Park, Calif. Interim Scientific Rept., May 1966, 65 p. Scientific Rept. 1 AFCRL 66-355. AD 634154.

...This report consists of an introductory portion followed by separate sections concerned with aircraft observations of jet-stream and mountain-wave turbulence. Statistical relationships between airline pilots' reports of turbulence and concurrent meteorological conditions, and the feasibility of measuring turbulence from rising balloons tracked by FPS-16 missile-tracking radar. The aircraft data show that turbulence correlates well with the horizontal wind-direction shear measured on the mesoscale. Recent aircraft data also re-emphasize the hazards to aircraft that exist in mountain-wave turbulence. A number of meteorological quantities were correlated with frequencies of turbulence determined from pilot reports. Contingency tables of turbulence frequency as a function of vertical shear and lapse rate indicate that lapse rate is not significant in the manner indicated by Richardson's number. From meteorological data and empirical equations, expected frequencies of turbulence over the United States were computed and compared with observed frequencies. (Author)

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67. Franco, M. The Use of SST Radar for the Detection of High Altitude Phenomena (WR-009). Lockheed-California Co., Burbank. Rept. No. LR-20237, Nov 1966, 8 p. Contract FA-SF-66-7. AD 817904L.

...This report deals largely with one major area of high altitude phenomenon, Clear Air Turbulence and its detection. Recent theoretical studies and some experimentation indicate the possible use of C- or X-band radar as a detector of CAT anomalies. Radars of this frequency have frequently detected so-called angels which were considered to be produced by high temperature air causing refractive surfaces off which the radar bounces. It can also be theorized that the varying refractive indices in turbulent air may be detected. (from Author Abst)

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68. Franken, P.A., Jenny, J.A. and Rank, D.M. Airborne Laser Radar Investigations of Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 132-133. DAS 51.5 W277pro.

## 68. (cont)

...Conclusions based on the airborne experiments with laser radars are summarized in this paper. (ALS)

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69. George, Joseph J. Airline Practices in Forecasting Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C. Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 172-180; 197. figs, refs. DAS M51.5 N277pro.

...The flight problems of Clear Air Turbulence are brought into focus. The forecast problem is reviewed and airline practices in forecasting are described. It is demonstrated that adding the requirement of an axis of minimum temperature at levels from 300 to 200 mb reduces the average forecast box appreciably as well as adding accuracy. A practical forecast procedure is suggested. (Author)

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70. Gibson, Frank W. Some Application of the Laser as an Atmospheric Probe. (Issued as AMS/AIAA Conference on Aerospace Meteorology, Los Angeles, Calif., Mar 28-31, 1966) AMS/AIAA papers (preprint) 66-374, Mar 1966, 20 p, figs, refs, eqns. DAS M(C55) A512lp 66-374.

...Investigations are being conducted to determine the possibility of detecting Clear Air Turbulence (CAT) with laser optical radars. Experiments in the laboratory and afield have shown evidence of variations in particle concentrations, but no positive identification of turbulence or correlations of rough flying have been made. The feasibility of measuring wind velocity components with a laser doppler radar is being examined. Provided sufficient aerosol scattering is available, spectral frequency analysis should give a more direct measurement of turbulence. A laser searchlight technique has been used to measure atmospheric density vertically up to 60 km. The method uses the Rayleigh scattering theory to deduce the molecular number density from the number of backscattered photons detected. (Author)

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71. Greene, Joel; Roberto, E. and Lewinstein, M. Early Warning of Clear Air Turbulence by Photometric Measurements. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 163-171. figs, refs, eqs. DAS M51.5 N277pro.

...Deals with techniques of photometric measurements of starlight variations which propagate along a line of sight coincident with the flight profile of a jet aircraft. Thus, a CAT "volume" intersecting this flight path may be detected at some prior point in time and compared to nonturbulent measurements. A star tracker will produce information which by statistical processing will establish a threshold for advance warning of CAT. Recommendations are presented for nighttime feasibility tests to be made with operational hardware under controlled conditions. Daytime tests requiring the measurement of weak bodies in high ambient conditions poses severe problems. (Author)

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72. Jefferson, G.J. An Incident of Severe Low-Level Turbulence, The Met. Mag. No. 1130, Vol. 95, Met. Office, London, Eng. Sep 1966, pp 279-285. DAS M(05) G786a.

...On 14 April 1966, several aircraft in the vicinity of Akrotiri (Cyprus), reported severe turbulence. A Canberra fitted with an accelerometer flew over the area at an altitude of 8500 ft and was completely overturned. The accelerometer readings were observed between +7g and -3g. (ALS)

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73. Kadlec, Paul W. Exploration of the Relationship between Atmospheric Temperature Change and Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 41-50, figs, tables, refs. DAS M51.5 N277pro.

...Certain atmospheric temperature changes have been observed to be a factor in detecting the occurrence of Clear Air Turbulence, especially at jet altitudes above 25,000 ft. Data for this study were collected by the author on 140 flights during the year while riding as an extra crew member in the cockpit of airline and military jet aircraft. The aircraft instrumentation in the research program included a portable test instrument to detect temperature changes as well as the normal components of an air data system and temperature sensors. A

## 73. (cont)

comparison between several rates of temperature change was made in an effort to determine which would indicate actual flight conditions most efficiently. From flight observations using the portable test instrument, a rate of temperature change of  $1.0^{\circ}\text{C}/\text{min}$  was found to be the most useful criterion for correctly indicating flight conditions in the majority of cases. (Author)

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74. Kadlec, Paul W. Flight Observations of Atmospheric Turbulence. Eastern Air Lines, Inc., Miami, Fla., Meteorology Dept., Contract FA66WA-1449, Final Report, Jun 1966, 52 p, figs, photos, charts, table, refs. DAS M(051) 213f1.

...This is a report on continuation of in-flight examination of meteorological parameters associated with non-convective turbulence initiated in December 1960. Results of analysis of data collected on 963 flights by a research meteorologist riding in the cockpit of airline and military jet aircraft are summarized. The equipment and procedures and three cloud-pattern models that associate cirrus formed by jet streams with turbulence are described. A refinement in the theory indicates that a rate of temperature change of  $1.0^{\circ}\text{C}/\text{min}$  with a total change of  $2.0^{\circ}\text{C}$  is the most effective combination for detecting impending turbulence. It was found that clear air vortices formed in the precipitation-free area below the base of severe thunderstorms may produce turbulence capable of upsetting multi-engine jet aircraft. An airborne portable scintillometer described and shown in a photograph was flight tested. (DBK)

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75. Kao, S.K. and Sizoo, A.H. Analysis of Clear Air Turbulence Near the Jet Stream. J. Geophys. Res., Wash., D.C., Vol. 71 No. 15, 15 Aug 1966, pp 3799-3805, figs, tables, refs. DAS P Col.

...Flights of Project Jet Stream (1956-1957) have been analyzed with respect to various meteorological parameters and Clear Air Turbulence near the jet stream in order to find a method for the prediction of high level turbulence in the atmosphere. It is found that the horizontal velocity convergence has a pronounced effect on turbulence in the atmosphere. The percentage of turbulence occurrence and the turbulence intensity generally increase with increasing horizontal velocity convergence and may be approximated by an exponential function

## 75. (cont)

of the latter. An analysis is also made of the distribution of turbulence in the vicinity of the jet stream and the effect of jet stream curvature on high level turbulence. It is found that (1) the percentage of turbulence occurrence is higher to the north than to the south of the jet and the percentage of turbulence occurrence is greater below the jet core than above it, and (2) curved jets have a higher percentage of turbulence distribution than straight jets and the straight segment east of a cyclonic jet has a higher percentage of turbulence occurrences than the straight segment west of it. (Author)

See also: Sizoo, Antoine Henri. A Study of Clear Air Turbulence Near the Jet Stream. Utah Univ., Salt Lake City, Dept. of Meteorology. Jun 1966, 22 p, Contract AF 33(608)-1288. AD 481944.

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76. Lederer, Jerome. Economic Aspects of Flight in Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings. N.Y. Society of Automotive Engineers, 1966. pp 35-39. DAS M51.5 N277pro.

...Presents an initial attempt to estimate the economic effects of turbulence on airline operations from the standpoint of costs of temporary grounding for inspections and repairs, cost of training crews to cope with turbulence, the cost of disseminating information on turbulence, and the cost of injuries sustained by passengers. The data were obtained from several airlines covering a wide geographic area. The costs were difficult to ascertain because the accounting systems do not readily separate the cost elements from several associated costs of operation. The information was extrapolated for all the major airlines to arrive at an estimate that turbulence costs about \$6.00 per flight. (Author)

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77. Thermitte, Roger. Probing Air Motion by Doppler Analysis of Radar Clear Air Returns, IBKTM-NSSL. Report No. 26, Norman, Oklahoma, Tech Note 46 NSSL 26, May 1966, 37 p. DAS M(055)v 5832re No. 26.

...A Doppler radar has been used in central Oklahoma to probe the motion of invisible targets usually referred to as "angels". The large density of targets detected on certain days suggests the presence of a dense atmospheric "plankton"

## 77. (cont)

drifting with the air. Uniform motion for all the targets in the area surveyed by the radar beam is confirmed by the systematic pattern of target radial motions as a function of radar beam azimuth. Target horizontal motion direction and speed are derived from the radial velocity-azimuth patterns and interpreted as horizontal wind. The small vertical motion of targets is also estimated from the data. This technique is applied to the analysis of wind variance and the study of a low-level jet. (Author)

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78. Loving, Neal V. High Altitude Air Turbulence (HICAT): A Menace to the Aerial Highway. (Issued as AMS/AIAA Conference on Aerospace Meteorology, Los Angeles, Calif., Mar 28-31, 1966, AMS/AIAA Papers (preprint), 66-362, Mar 1966. 16 p, figs, refs, eqs.) DAS M(055)A 5121p 66-362.

...Due to lack of airborne Clear Air Turbulence (CAT) detection capability and high operating speeds which disallow evasive action, future aerospace vehicles must possess the inherent structural integrity for repeated high speed penetration of CAT. Hence, there is a requirement to identify the types of turbulence at high altitudes and to measure the intensity and wavelength of each. To fulfill this requirement, a High Altitude Clear Air Turbulence (HICAT) Project has been initiated to provide accurate, continuous wavelength CAT measurements in the altitude range of 40,000 to 70,000 ft. In the work accomplished thus far, an analog FM instrumentation system utilizing a fixed-vane gust probe and a 7-hr recording was installed aboard an Air Force U-2. Actual vertical gust velocity time histories containing gust wavelengths from 70 to 2500 ft have been calculated from the power spectra. Extended HICAT program will utilize a new digital (PCM) instrumentation system. This system will include a stable platform which will greatly improve the precision of HICAT measurements and permit turbulence wavelengths in excess of 12,000 ft to be measured. (Author)

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79. Mancuso, R.L. and R.M. Endlich. Clear Air Turbulence Frequency as a Function of Wind Shear and Deformation. Monthly Weather Rev. Vol. 94, No. 9, Sep 1966, pp 581-585, 13 refs, 2 figs, 4 tables, formulae. DAS M(05)v 587m.

## 79. (cont)

...The probability is determined that an aircraft will encounter moderate or severe high-level turbulence during a 100-mi flight segment when particular values of certain meteorological quantities exist in that locality. The turbulence data used are pilot reports collected by the U.S. Weather Bureau Clear Air Turbulence Project for March 12-24, 1962 and February 4-9, 1963. The meteorological quantities which were computed from standard data include vertical vector wind shear, vertical wind direction shear, temperature lapse rate, horizontal wind shear, vorticity, and resultant deformation. A correlation of 0.45 was found between turbulence frequency and the product of vertical vector wind shear and deformation. This value is the highest correlation found so far with data of this type. The product of wind shear and deformation is an important factor in the development of fronts. (from Author Abst.)

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80. McConathy, Donald. Case Study of CAT in the Rockies, Pennsylvania State Univ, Minerals Industries Experiment Station, Contract Cwb-10926, Final Report, Sep 1, 1964-Feb 28, 1966, issued Jul 15, 1966. 27 p, figs, table, refs. DAS M(051) RP415fic.

...Presents a detailed 3-dimensional analysis of the fields of wind, temperature, and Richardson number over the Rocky Mountains for 00Z, April 11, 1963. At this time, the usual rawinsonde information was supplemented by winds, temperature, and turbulence reports from specially-instrumented aircraft. The reports of turbulence correspond in a general way to regions of low Richardson number associated with a strong internal front. However, there is no agreement in detail. This may be due to lack of precision in the turbulence reports and insufficient resolution in the wind and temperature data. Distributions of actual and geostrophic Richardson number agree with each other in general, but not in detail. Most of the turbulence reports coincide with high terrain features. (Author)

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81. McLean, James C., Jr. Synoptic Analysis of Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C. Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 28-34; 54. fig, refs. DAS M51.5 N277pro

## 81. (cont)

...It is hypothesized that frontal surfaces between air masses of differing characteristics are the source of much of the Clear Air Turbulence encountered by aircraft in the upper troposphere and lower stratosphere. These fronts can be detected on detailed soundings as adiabatic zones of mixing and traced over geographic areas by isentropic analysis. (Author)

82. Moore, Richard L. (Douglas Aircraft Co., Inc), and Krishnamurti, T.N. A Theory of Generation of Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C. Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 13-27, figs, refs, eqs. DAS M51.5 N277proc.

...Presents additional information of a theoretical nature and a synoptic case study concerning the nature of the generation of Clear Air Turbulence. The hypothesis in this paper is that (a) shear is generated rapidly in a specific region of the atmosphere, (b) the shear reaches a critical value and the flow field becomes turbulent, (c) the turbulent flow field, in the form of a cell or eddy, is carried away from the source region and gradually decays. The theory on which the prediction of shear is based is developed on a nonlinear basis to show that if convection of vorticity is neglected, the vertical component of the vorticity depends quadratically with time on the solenoids of temperature and divergence of velocity, plus another smaller term. Thus, the horizontal shear of the velocity may be expected in certain large-scale synoptic situations to grow nonlinearly. (Author)

For similar report, see also:

Moore, Richard L. and Krishnamurti, T.N.  
Atmospheric Clear Air Turbulence. Nature,  
 London 209 (5022):452-464, Jan 29, 1966.  
 Figs, refs, eqs. DAS P Col

...Synoptic evidence suggests that Clear Air Turbulence (CAT) is associated with certain well recognized large scale patterns in which large vertical shears arise. It is suggested here that CAT is formed in the following phase; a) shear is generated rapidly in some region of the atmosphere to be called the "source region," b) the shear reaches a critical value and the flow field becomes turbulent, then c) the turbulent flow field is carried away from the source region and gradually decays. It is shown how shear is measured in terms of the vorticity vector. To test the proposed hypotheses with a specific example curves of constant value of the Jacobian

82. (cont)

of temperature and divergence of the velocity at 300 mb are drawn for a particular well-documented observed case of CAT. The reported cases of severe turbulence are all seen to be close to a center of marked negative value. Later reports of moderate turbulence are not inconsistent with the hypothesis. (RB)

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83. Mount, Wayne D. and Fow, B. Richard. Results Applicable to Clear Air Turbulence Detection Using a Millimeter Wave Radiometer Probe. In: National Air Meeting on Clear Air Turbulence, Wash., D.C. Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 119-124, figs, refs, eqs. DAS M51.5 N277pro.

...Experimental results show that it is possible to obtain a remote measure of the temperature and temperature gradient by using a millimeter wave radiometer probe. Temperature gradients typically associated with CAT are formulated in a model for computing radiometric temperatures that an inflight remote sensor would detect. These results show that a millimeter wave radiometric system could be used more effectively than a direct temperature measuring system to provide a more reliable and earlier warning of impending Clear Air Turbulence. (Author)

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84. Norman, Sol M. and Macoy, Norman H. Inference of Clear Air Turbulence by Means of an Airborne Infrared System, Journal of Aircraft, Vol. 3, No. 4, Jul-Aug 1966, pp 289-296, 12 refs, 9 figs, table. DAS P Col

...Various researchers have shown that some forms of clear air turbulence are characterized by temperature gradients, of the order of 3° to 5°C. A prototype airborne infrared system has been developed to remotely detect this type of temperature discontinuity at ranges in excess of 10 miles. The detection system is a novel infrared spectrometer consisting of a rocking Fabry-Perot etalon that scans its narrow wavelength pass band from approximately 13.5 to 14.5  $\mu$  at the edge of the CO<sub>2</sub> absorption band. Since the infrared transmission is a strong function of wavelength in this spectral region, the instrument sees sequentially shorter atmospheric path lengths during the course of the scan. This permits a temperature discontinuity ahead of the aircraft to be detected by a change

## 84. (cont)

in the normal instrument output produced during a scan. The instrument is described in detail, and a comparison is made between it and other types of infrared techniques for this application. Typical output wave shapes for various idealized temperature discontinuities are presented, as well as results from initial field trials. (Author)

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85. Paulsen, Wilbur H. Investigation of Techniques for Detecting Clear Air Turbulence, AFCRL. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, proceedings, N.Y. Society of Automotive Engineers, 1966. pp 51-54.  
DAS 51.5 M277pro.

...A review is made of the various approaches considered in trying to develop an instrument capable of detecting CAT ahead of an aircraft. Because of the widespread regions in which CAT can occur and its often limited size, an airborne instrument is felt to be necessary to provide the pilot with sufficiently accurate and timely data to permit appropriate action to be taken to minimize its effect on the aircraft. While progress had been understandably slow, the outlook is not as black as it was a few years ago and the interests and efforts of many more people, plus advances in technology, enhance the possibilities of finding a solution to the CAT problem.  
(Author)

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86. Pchelko, I.G. Turbulentnost' pri iasnom nebe. [Clear Air Turbulence.] Gidromet. Nauch-Issled. Tsentr, SSSR. Meteorologiya i Gidrologiya, Moscow, No. 12:10-18, Dec 1966, figs, table, refs. DAS P Col

Translation available under NASA-N67-30407.

...The incidence of Clear Air Turbulence recorded during four 5-day periods in 1964 and 1965 over the continental part of the USSR and over the socialist countries of Europe is analyzed. The probability of bumpiness over the USSR is small, amounting to an average of 5.6%. In Dec 1964 and Mar 1965, there were days in which the mean was exceeded considerably, 12.3 and 19.9%, respectively. The geographical and horizontal distribution of zones of high frequency of turbulence depends upon season. The horizontal extension of bumpiness zones

86. (cont)

ranges in most cases (54%) from several kilometers to 100 km and up to 200 km in 78% of the cases. Over the European USSR and over the socialist countries of Europe, the maximum turbulence frequency occurs during southwest wind; over Siberia, during northwest wind; and over Central Asia, west wind. (ILD)

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87. Polve, James H. Theoretical Investigation and Optimization of an Airplane Gust Alleviation System. Arizona Univ., Tucson. Doctoral Thesis, 1966, 140 p. Contract AF 33(608)-1205. AD 481453.

...The system calls for a method to sense the air turbulence or gusts as changes in angle and to relay this information through an appropriate servomechanism control to an alleviation device to cause it to alleviate the effects of the turbulence upon the airplane. These effects are manifested as changes in load factor, and a principal goal of this investigation was to optimize the attenuation of these load factor variations. The servomechanism control regulates the input to the alleviation device through proportional, derivative, and integral control. The problem resolved itself into finding the gains of these control parameters and to show how much attenuation of the load factor could be achieved across the entire gust frequency spectrum. (part Author Abst)

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88. Pritchard, Francis E. The Turbulence and Terrain Environments Affecting Low-Altitude, High-Speed Flight. Cornell Aeronautical Lab., Inc., Buffalo, N.Y. Rept. No. CAL-FDM-393, Jul 1966, 46 p. AD 486689.

...The appropriate statistical theory and the data are reviewed. Representative data and, where possible, models of the turbulence and terrain are presented. For the turbulence environment a valid and useful model is presented. Here, the approach was to develop a model no more complex than current knowledge and data warrant. With regard to the terrain, no model is comparable to the one for turbulence. The primary reason for this is that the terrain statistics, theory, and data have not been developed to the same level, although very recent research has considerably improved the situation. (Author)

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89. Reiter, Elmar R. Clear Air Turbulence: Problems and Solutions (A State-of-the-Art Report) In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 5-12; 27, figs, refs, eqs. DAS M51.5 N277pro.

...A summary is given of the present state of knowledge on the physical causes of Clear Air Turbulence (CAT). Special reference is made to recent measurement results from Project TOPCAT. Implications of these flight investigations, which were made over Australia, on remote sensing of CAT, and on the planning of future research efforts are outlined. (Author)

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90. Reiter, Elmar R. et al. Structure of Clear-Air Turbulence Derived from TOPCAT Aircraft Measurements. J. Atmospheric Sci. Boston, Vol. 23, No. 2, Mar 1966, pp 206-212, figs. 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000.

Similar article published in 1965 (see No. 41).

...Measurements of Clear-Air-Turbulence spectra conducted by a Canberra aircraft over Australia between Jul and Oct 1963, reveal the existence of a wavelength region from somewhat less than 1000 ft, in which the atmosphere receives turbulent energy. It is suggested that this energy stems from gravitational shearing waves which break up into turbulent eddies below a critical wavelength. (part Author Abst.)

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91. Rosenberg, Paul. Clear Air Turbulence Detection and Warning. Paul Rosenberg Assoc. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966, pp 40-43. DAS M51.5 N277pro.

...Possible methods for the advance detection and warning of Clear Air Turbulence by airborne devices are surveyed briefly. These include: active use of radar, microwaves, infrared and visible portions of the electromagnetic spectrum; passive use of infrared millimeter waves and visible portions of the electromagnetic spectrum; passive use of infrared millimeter waves and visible light; air temperature probes; electric field measurements; electric charging of aircraft; microbarometric measurements etc. The state-of-the-art of CAT detection and warning is still exploratory. No method has yet been demonstrated to give advance warning of CAT with

91. (cont)

a confidence level sufficient to justify operational use, and too little is known about the physical parameters of CAT to enable any one method of detection and warning to be singled out as the most promising. More basic research on the physics and meteorology of CAT itself is needed. (Author)

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92. Sadoff, Melvin and Bray, S. Summary of NASA Research on Jet Transport Control Problems in Severe Turbulence. Journal of Aircraft, Vol. 3, No. 3, May-Jun 1966, pp 193-200. DAS P Col.

...Research results from analytical, piloted-simulator, and flight studies have made it possible to evaluate the relative significance of cockpit accelerations, stability and control characteristics, and handling qualities in the upset and recovery problems of swept-wing jet transports encountering severe turbulence. Results of simulator tests, conducted on a device capable of reproducing cockpit acceleration response to thunderstorm turbulence, indicated that cockpit accelerations (including vibration caused by a predominant fuselage bending mode) were distracting to the pilots and impaired their normal instrument scan pattern. These acceleration effects appeared to be primary contributing factors to several incidents involving marginal and complete loss of control observed during pilot performance of a complex task in the simulator. Results and comments from a number of airline pilots exposed to the simulation demonstrated the training potential of this type of simulator. (part Author Abst.)

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93. Sastry, P.S.N. Note on Evaluation of the Richardson Number in Relation to Forecasting Clear Air Turbulence. Indian J. Meteor. & Geophysics, Vol. 17, No. 3, pp 415-418, Jul 1966. DAS M(05) I391.

...For forecasting Clear Air Turbulence Richardson's number is one of the widely used parameters. With increase in air traffic and aircraft operating at very high altitudes, the necessity for providing accurate information on turbulence in clear air is keenly felt. (Author)

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94. Saxton, David W. Nature and Causes of Clear Air Turbulence. U.S. Air Weather Service, Scott AFB, Ill., American Institute of Aeronautics & Astronautics, 3rd Annual Meeting, Boston, Nov 29-Dec 2, 1966, Paper 66-966, 6 p. DAS M(055) A5121p 66-966.

...The characteristics of CAT are discussed in terms of turbulence-measuring systems and data reduction methods. The spectral density technique of data reduction, which has largely replaced the discrete gust method, is used to illustrate the interaction between the aircraft and turbulence and to highlight the difference between undulance and turbulence. Internal gravity waves and the conditions which appear favorable for their amplification and breakdown into isotropic turbulence are discussed. Meteorological data available to diagnose and forecast CAT are evaluated and a comparison is made between conventional rawinsonde data and wind data obtained with precision missile-tracking radar. A recent XB-70A encounter with CAT is used to illustrate the challenge of the future. (Author)

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95. Shur, G.M. The Spectral Structure of Turbulence in a Free Atmosphere Based on Data Obtained by Aircraft. Redstone Scientific Information Center, Redstone Arsenal, Ala. Rept. No. RSIC-543, Jun 1966, 18 p. AD 637728.

...On the basis of the analysis of experimental data on turbulence obtained by a TU-104 aircraft, this article examines the energy spectrum of the vertical velocity component of turbulent gusts in a temperature-stratified atmosphere. The relationship between the spectra of the vertical and horizontal component in a stably stratified atmosphere is also examined. The measurements of the gust loads in a narrow band of frequencies (wave numbers) make it possible to obtain the dispersions in the velocities of gusts in a wide range of scales. (Author)

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96. Smirnova, G.A. Passive-Reflector Experiments in Radar Measurement of the Turbulence of the Clear Sky. Am. Meteorol. Soc., Boston, Mass. Res. Translation, Rept. No. T-R-517, Jan 1966, 16 p. Contract No. AF 19(628)-3880. AD 630553.

...Some results of radar investigation of the atmospheric turbulence of the clear sky are presented and compared with data from aircraft observations. (Author)

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97. Steiner, Roy. Review of NASA High Altitude Clear-Air Turbulence Sampling Programs. AIAA Paper No. 65-13, Jan 1965, 11 p. J. of Aircraft 3(1):48-52, Jan/Feb 1966. DAS P Col.

...The NASA sample of Clear Air Turbulence from flight operations of U-2 airplanes has been extended to nearly 320,000 miles for altitudes between 20,000 and 75,000 ft. The flight measurements indicate that for the higher altitudes (40,000 to 75,000 ft) turbulence is both less frequent and less severe than for the lower altitudes (20,000 to 40,000 ft). Turbulence appears to be present at the high altitudes less than 1% of the time. The intensity of the turbulence decreases in an orderly pattern with increasing altitude and less than 50% of the turbulent areas exceeded 10 miles in length. The maximum measured value of derived gust velocity was 20 fps at an altitude of 52,000 ft. On the basis of rough approximations, this value corresponds to a true gust velocity of 58 fps. (Author)

See also:

Summary of Atmospheric Turbulence Data,  
NASA Conference on Aircraft Operating  
Problems, "A Compilation of the Papers  
Presented," Langley Research Center,  
Langley, Va. May 10-12, 1965, pp 19-27.  
IPB Files.

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98. TenBroek, H.W. and Seashore, C.R. Study of Low Frequency Electrical Characteristics of Clear Air Turbulence and Storm Front Centers. Honeywell, Inc., St. Paul, Minn., Systems & Research Div., Contract AF 19(628)-5060, Final Report, Mar 15-Sep 15, 1965, issued Feb 1966. 123 p, figs, charts, tables, refs, eqs. (AFCLR-66-240). DAS (M(051) H772fist). AD 636050.

...This report covers work done in investigating the low frequency electrostatic field characteristics of Clear Air Turbulence and storm front regions. The general theory describing the field sensing antennae is presented in addition to the practical aspects of those antennae actually utilized in the program. The electronic instrumentation used in ridge-line turbulence encounter and three storm-front flights are analyzed with respect to frequency content in decade bandwidths from 0.1 to 10,000 cps. Results from the turbulence flight reveal signals due to the turbulence which differ from pre- and post-encounter norms and present the possibility of anticipating the encounter. (Author)

98. (cont)

See also:

TenBroek, H.W. and Seashore, C.R. Low-Frequency Electrical Characteristics of Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966, Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 84-96, figs, tables, refs, eqs. DAS M51.5 H277pro.

...The results of an investigation of the low frequency electrostatic field characteristics of Clear Air Turbulence are presented. Brief descriptions are included of the general theory and practical aspects of the field sensing antennae used during the program and the electronic instrumentation used in data-gathering flights and subsequent data reduction. The data from a ridgeline turbulence encounter are analyzed with respect to frequency content in the decade bandwidths from 0.1 cps to 2000 cps. The results reveal turbulence generated signals in the 0.1-10.0 cps region which differ from pre- and post-encounter norms, presenting the possibility of anticipating the encounter. The direction of future effort is described. (Author)

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99. U.S. Air Force, Cambridge Res. Labs. Radar Detection of Clear Air Turbulence. Meteorology Lab., Office of Aerospace Research, Research Review, 5(6):15-17, Aug 1966. Photos. IPB Files.

...Reports briefly that experiments are being conducted at the Joint Air Force-NASA radar facility at Wallops Is., Va. Experiments that may lead to a ground-based radar network for Clear Air Turbulence (CAT) warning are being conducted by AFCRL. The AFCRL program is not only concerned with CAT detection, but with obtaining a general understanding of the atmospheric processes which result in radar echoes from clear air. In turn, this understanding can provide a theoretical basis for approaching the CAT detection problem. One suggested radar network configuration would have ground stations spaced 100 to 200 mi apart. The beam from one antenna would scan at a low angle in the direction of another antenna. Any CAT in the air corridor between the two antennas would cause some of the energy from one antenna to be reflected to the other. (RS)

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100. Vinnichenko, N.K. [Clear Air Turbulence at the Heights of 6-12 km] Turbulentnost' v iasnom nebe na vysotakh 6-12 km. Akademiia Nauk SSSR, Izvestiia Fizika Atmosfery i Okeana 2(11:1135-1141, Nov 1966, figs, refs). Transl. into English in corresponding issue of its Izvestiya Atmospheric and Oceanic Physics, issued Wash., D.C. DAS P Col.

...Experimental data about power spectra of horizontal component of CAT in the upper troposphere are presented. It is shown that: 1) the relationship of meso- and micro-scale spectra is not uniform and 2) mesoscale spectra can be extrapolated into the high frequency range following the " $-5/3$  law" only in rare cases. Three types of micro-scale spectra are discussed. The influence of degenerating gravity waves on the character of turbulence spectra is described. (Author)

101. Vinnichenko, N.K., Pinus, N.Z. and Shur, G.N. Nekotorye dannye o turbulentnosti, vyzyvaiushchei bol'tanku samoletov, v verkhnei troposfere i stratosfere. [Some Data on the Turbulence in the Upper Troposphere and Stratosphere which causes Aircraft Bumping. Meteorologiya i gidrologiya, No. 11, 1966, pp 26-33. DAS M(05) M589.

In Russian

...Recently a great deal of experimental data has been accumulated in the Soviet Union on Clear Air Turbulence (CAT) from flights at heights of 11-12 km. Radiosonde data are also available on the distribution of turbulence up to heights of 25-30 km. In order to obtain significant qualitative data on the spectral and correlative characteristics of turbulence, computers are required. In this study, turbulence is treated only from the point of view of its effect on aircraft. Vertical profiles of the frequency of turbulence causing airplanes to buffet in various geographical regions of the world, constructed from data from airplane observations, are compared. (Author)

102. Vorontsov, P.A. Program and Techniques of Atmospheric Turbulence Research on Mountainous Helicopter Routes. Leningrad. Glaunala Geofizicheskaya Observatoriia Trudy, No. 171:20-31, 1965, Trans. by AMS for AFCL, OAR, T-R-630, 3 refs, 4 figs. Contract AF 19(628)-3880, Oct 1966. AD 643,800.

## 102. (cont)

...The following problems were presented: a) to generalize the available experience in aviation weather forecasting for helicopter flights, b) to study atmospheric turbulence on mountainous routes with specially equipped helicopters and airplanes and passenger helicopters, c) to discuss flight conditions on a given route with the flight personnel, and d) to have the forecasters of the Aviation Weather Stations servicing helicopter flights engage in a study of the flight conditions on the route and in a refinement of the existing operating instructions on the forecasting of buffeting.  
(Author)

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103. Wells, E.W. Project TOPCAT: Summary of Meteorological Observations and Aircraft Measurements during Routine Flights in the Australian Jet Stream. Royal Aircraft Establishment, Farnborough (England). Tech Rept. No. TR-66122, Apr 1966, 103 p. AD 640375.

...A number of flights were made over set tracks and heights to measure Clear Air Turbulence in the vicinity of the Flinders Ranges in South Australia. Details of the meteorological observations and flight paths, and measurements of wind, temperature, and turbulence obtained from the aircraft instrumentation are presented. Wind and temperature gradients were derived for cross sections on the upwind and downwind sides of the ranges and a comparison made of the intensity of turbulence between the two sides. (Author)

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104. Wormser, Eric M. Remote Detection of Clear Air Turbulence by Means of Airborne Infrared Instruments. Barnes Engr. Co. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966. Proceedings, N.Y. Society of Automotive Engineers, 1966. pp 125-131, figs, refs. DAS M51.5 N277pro.

...Air temperature gradients are frequently associated with CAT. Radiation measuring instruments have already been used for the remote sensing of air temperature. A suitably designed instrument should give adequate warning of turbulence regions ahead and provide an opportunity for their avoidance. A spectral-scanning infrared radiometer has been designed for this purpose and is described in this paper. Extensive ground tests have been conducted, including making atmospheric temperature analyses in horizontal and vertical directions.

104. (cont.)

Mountaintop tests are being planned and airborne tests will follow. Detection ranges of 25 mi are anticipated. (Author)

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105. Zirkle, Raymond E., Jr. The Feasibility of Optical Radar to Detect Clear Air Turbulence. In: National Air Meeting on Clear Air Turbulence, Wash., D.C., Feb 23-24, 1966. Proceedings, N.Y., Society of Automotive Engineers, 1966. pp 55-68, figs, tables, refs, eqs. DAS M51.5 N277pro.

...Pulsed ruby laser optical radars were used to examine the feasibility of turbulence detection in laboratory test chambers and afield. Many returns obtained showed evidence of particle concentration variations, but none were identified as interactions with either turbulence or correlates of rough flying. Calculations and recently reported evidence show that cw laser Doppler Optars might eventually measure wind velocity components and gust spectra. (Author)

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106. Zirkle, Raymond E., Jr. Study of Techniques for Detection and Measurement of Clear Air Turbulence. Honeywell, Inc., Roseville, Minn. Systems & Research Center. Rept. No. 1540-FRI, Jan 1966, 135 p. Contract No. AF 19(628)-2376, AD 636325.

...Two general ways in which laser optical radar (OPTAR) might be useful for Clear Air Turbulence detection were examined. The first method involves spectral analysis of Doppler-shifted light, backscattered by moving particles, to provide measures of average and gust spectrum velocity components. The second method involves the mapping of particle formations arrayed in the atmosphere by correlates of rough flying conditions such as wind shear, the jet stream, mountain waves, etc. Calculations show that the particulate matter of the troposphere which dominates optical backscatter is dynamically suitable for the mapping of wind motions consistent with anticipated requirements of CAT detection. Experiments by other groups have shown that laser Doppler methods can measure particle velocities in the laboratory. (Author)

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107. Atlas, D. et al. Bistatic Microwave Probing of a Refractively Perturbed Clear Atmosphere. University of Chicago, Dept. of the Geophysical Sciences, Tech. Report No. 1, Chicago, Ill., 15 May 1967, 43 p, 16 refs, 9 figs, 10 eqs. DAS M(055) C532re, No. 1.

...Calculations are carried out to predict the signal levels to be received by bistatic scatter systems (a microwave transmitter and receiver) from vertically thin layers of the clear atmosphere that are turbulently perturbed. This is done by measuring the refractivity perturbations. The results indicate that the model system can detect regions having only modest perturbations. Clear Air Turbulence can be readily detected at least in the vicinity of the mid-path. (Author)

108. Boone, Joseph P. High Altitude Critical Atmospheric Turbulence Data System. Air Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio. Final Tech. Rept. 15 Feb 65-10 Feb 66. Rept. No. AFFDL-TR-67-1, May 1967, 29 p. AD 816976.

...The purpose of this report is to provide a synopsis of the data system designed to measure, record, and process high altitude critical atmospheric turbulence (HICAT) data. The HICAT project is to measure gust velocity components in the altitude range of 40 to 70 thousand feet in several world areas. The goal is a statistical definition of the 'Roughness' of the atmosphere which can be applied to design requirements for advanced aircraft structures. A pulse code modulation airborne system is described. Highly accurate sensors and components, including an inertial platform, are used aboard a WU-2 test aircraft in an attempt to resolve fine scale forces, accelerations, and aircraft motions in the atmospheric gust field. The magnetic tapes and other pertinent information are sent to a data-processing ground station for generation of a computer-compatible tape, processing, and detailed analysis. Power spectral functions of the gust components are of major interest. Output data are correlated with meteorological and geographical data associated with the test site. (Author)

109. Brochet, P. and Gland, H. Contribution à l'étude statistique of the turbulence en air clair zone Europe-Méditerranée. [Contribution to the Statistical Study of a Clear Air Turbulence Zone in Mediterranean Europe.] La Meteorologie, Ser. 4, Paris, No. 31, pp 3-23, Jan/Mar 1966, issued 1967, figs, tables, refs. French, English, and Spanish summaries p 3. DAS M(05) M589v.

In French

...In 1964 and 1965 ICAO organized 4 worldwide periods of investigations on clear sky turbulence. Here are given some results for the first period concerning a part of the area for which the Meteorologie Nationale was responsible. (Author)

110. Bullen, N.I. A Review of Counting Accelerometer Data on Aircraft Gust Loads. Aeronautical Research Council, London (England). Current Papers, Rept. No. ARC-CP-933, 1967, 49 p. AD 819835.

...Counting accelerometer data collected over a period of several years on a number of passenger transport aircraft are summarized and the derived gust frequency distributions studied. The intensity of the turbulence encountered is compared with that observed by research aircraft in storms and clear air. (Author)

111. Colquhoun, J.R. A Summary of Four Five-Day Clear Air Turbulence Reporting Periods, Australian Meteorological Magazine, Vol. 15, 1967, pp 131-132, table, 6 refs. DAS M(05) A938.

...The paper summarizes the results of the ICAO short term high-level turbulence program covering the South Pacific region, which consisted of four periods each of five days duration in December 1964 and March, June, and September 1965. The results of these studies are published in the following four articles:

Clear Air Turbulence analysis over the South Pacific region for a five-day period in December 1964 by J.R. Colquhoun and V. Lynn Bourke, 4 figs, 25 tables, 7 refs, pp 47-72. (#103)

Clear Air Turbulence analysis over the South Pacific region for a five-day period in March 1965 by J.R. Colquhoun and V. Lynn Bourke, 2 figs, 24 tables, 8 refs, pp 73-93.

## 111. (cont)

Clear Air Turbulence analysis over the South Pacific region for a five-day period in June 1965 by J.R. Colquhoun, 2 figs, 21 tables, 8 refs, pp 94-111.

Clear Air Turbulence analysis over the South Pacific region for a five-day period in September 1965 by J.R. Colquhoun, 2 figs, 22 tables, 10 refs, pp 112-130. (Author)

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112. Crooks, Walter M. et al. Project HICAT, An Investigation of High Altitude Clear Air Turbulence, Volume I, II and III, Lockheed-California Co., Burbank, Final Rept. 12 Feb 65-10 Jul 67, Rept. No. LR-20771-Vol-1-III, AF FDL-TR-67-123, Vol. I-III, Nov 1967, 269 p. AD 824865, Vol. II AD 824904, Vol. III AD 825369.

...These reports describe the high altitude critical air turbulence (HICAT) flight investigation with primary emphasis upon the results achieved since 15 February 1965. On that date the program was redirected to utilize a new digital instrumentation system for the measurement of CAT in the wavelength range from about 100 feet to 60,000 feet. The program effort required the measurement of CAT velocity components at altitudes of 45,000 to 70,000 feet in seven geographic areas. Instrumentation carried aboard the HICAT aircraft, an Air Force U-2, consisted of a PCM system, an inertial navigation system, aerodynamic and aircraft response sensors including a fixed-vane gust probe, oscillograph recorder, and a digital magnetic tape recorder. The program objective is to determine the statistical characteristics of high altitude CAT so as to improve structural design criteria. Overall, 29.2 hours of high altitude CAT were located and recorded in flights covering over 256,000 miles from bases in California, Massachusetts, Alaska, Hawaii, Puerto Rico, New Zealand, and Australia. Actual vertical, lateral, and longitudinal gust velocity time histories were calculated from the measurements and used to obtain gust velocity power spectra. Meteorological factors were considered in categorizing and correlating data. (Part Author Abet).

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113. Dunn, J.W. et al. A Technique to Investigate the Nature of Clear Air Turbulence. Phase I. Computer Programming Manual, Final Report ESD-TR-67-292. The Research Triangle Institute, P.O. Box 12194, Res. Triangle Park, N.C., May 1967, 139 p. IPB Files.

## 113. (cont)

...Computer programs developed during the study of the nature of Clear Air Turbulence are presented. Program descriptions including the governing differential equations, finite difference formulations, and numerical analysis are given when appropriate. Logic diagrams and diagrams of finite difference grids are included. (Author)

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114. Dutton, John A. Belling the CAT in the Sky. Bull. Am. Meteorol. Soc., Vol. 48, No. 11, pp 813-820, Nov 1967. DAS M(05) A512b.

...The CAT in the sky, which has created a variety of problems since aviation began, is being attacked by an extensive measurement program sponsored by the United States Air Force under the code name ALLCAT. CAT data-gathering programs at all altitudes important to modern aviation are described, and some of the meteorological applications of the data are pointed out. It is shown how a properly instrumented airplane can be used to obtain actual gust velocities. The power spectral and exceedance statistic methods used to incorporate gust measurement data in aircraft design procedure are summarized and illustrated. The article concludes that the program will be an important step in taming all the CATS. (Author)

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115. Endlich, Roy M. et al. Forecasting Clear-Air Turbulence by Computer Techniques. Stanford Research Inst., Menlo Park, Calif., Final Rept. Sep 1967, 92 p. Contract FA-66-WA-1442. AD 664721.

...Pilot reports of Clear Air Turbulence from four special five-day reporting periods are used to investigate relationships between turbulence probability and meteorological factors. The meteorological analyses are made by computer on a 2.5-degrees latitude/longitude grid on the basis of standard upper-air observations. Analyses are made for the United States for altitude layers 50 mb (approximately 4000 ft) thick. Temperature analyses interpreted as thermal wind shear are used to compensate for wind observations missing in high-speed portions of the flow. The best meteorological indicators of turbulence are those related to the wind field. These indicators are vertical vector wind shear, deformation, and divergence. The analysis for turbulence is made from meteorological factors and pilot reports in terms of the

## 115. (cont)

probability of encountering significant turbulence (greater than light intensity) during flight segments 100 nautical miles long. Numerical forecasts of upper winds are prepared for the turbulence-reporting periods on the basis of advection and geostrophic departures. The departures are evaluated directly from the wind analyses by use of the balance equation. The advection uses upstream space differences and is tested in both explicit forms. (Author)

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116. Ettel, Michael Joseph. Numerical Forecasting of Clear Air Turbulence. Naval Postgraduate School, Monterey, Calif. Master's Thesis, Jun 1967, 172 p. AD 818985.

...There is much disagreement as to (1) what causes Clear Air Turbulence (turbulence which is not in or near convective clouds and is above 15,000 feet in altitude) and (2) which meteorological parameters can be used to detect and forecast its occurrence. The approach to this problem has been to relate not one parameter to Clear Air Turbulence (CAT), but various parameters. By summing these parameters, areas can be defined where there is a high probability of encountering CAT. Each parameter has been based on a statistical study which found a relationship with CAT. The parameters used were horizontal and vertical shear, curvature, kinetic energy, and their derivatives. The numerical forecasting program proposed here can be extended to the stratosphere when more reliable height and temperature fields are available. This program will have much more significance when intermediate forecast height fields, temperature fields, and a grid of much smaller mesh-length are available. (Author)

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117. Foltz, Harry P. Prediction of Clear Air Turbulence, Colorado State Univ., Ft. Collins, Dept. of Atmospheric Science, Atmospheric Science Paper No. 106, ESSA Contract WBG-59, Jan 1967, 145 p, figs, charts, tables, biblio. DAS M(055) C719at No. 106.

...Reports results of a study of lee waves carried out near Ft. Collins, Colo. in the spring of 1966 in which constant-level balloon trajectories, cloud photogrammetry, satellite photography, pilot turbulence reports, and rawinsonde data were used. Some of the results and cases observed principally by satellite are used to evaluate the CAT forecasting methods.

117. (cont)

By using the  $-5/3$  spectral density slope, the energy per cycle in the mesoscale, obtained theoretically, was related to that observed in the microscale and also to the degree of CAT. The results agreed well with actual reports of aircraft turbulence. Energy decay-times based upon computed dissipation rates using the  $-5/3$  law are consistent with the observed CAT patterns. The wavelengths of mountain lee waves observed by satellite are found to be close to those derived from theory. Graphical and computational aids were developed for forecasting CAT from rawinsonde and satellite information. (Author)

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118.

Gault, J.D. Low Altitude Atmospheric Turbulence LO-LOCAT Mid-Term Technical Data Analysis. Boeing Co., Wichita, Kans. 15 Apr 66-15 Jan 67, Aug 1967, 126 p. Contract AF 33(615)-3724. AD 820880.

...The contents of this report describe low-level critical air turbulence (LO-LOCAT) program accomplishments through 15 January 1967. These accomplishments cover the first four months of the one-year flight period. Four instrumented C-131B aircraft are measuring turbulence and meteorological data at absolute altitudes below 1000 feet while flying over specified routes located in California, Colorado, Kansas, and New York. At the mid-January point, approximately 130 hours of low-level turbulence data had been obtained. Analyses of these data are included showing gust amplitude and spectra experimental results consistent with atmospheric turbulence theory. (Author)

See also article in Canadian Aeronautics  
& Space Journal, Ottawa, Vol. 13, No. 7, pp  
307-314, Sep 1967.

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119.

Gland, H. (Met. National). Turbulence Exceptionnelle en air clair sur la France, Nov 5, 1965. [Unusual Clear Air Turbulence over France, Nov 5, 1965.] La Météorologie, Paris, Ser. 4, No. 82, pp 95-103, Apr/Jun 1966, issued 1967. Figs, refs. French, English, and Spanish summaries p 95. DAS PAM M(05) M560v.

**15 French**

...On the basis of numerous reports of CAT recorded by pilots on Nov 5, 1965, the author has investigated the general

## 119. (cont)

character of this phenomenon. The meteorological situation over France on Nov 5, 1965 is analyzed with the aid of a 300-mb surface map, a map showing the distribution of horizontal gradients of the zonal wind component at 300 mb, and a vertical cross section of the atmosphere, perpendicular to the plane of the jet stream. The distribution of observations of Clear Air Turbulence including intensity, altitude, and geographical location are shown on a map. The study shows an exceptional concentration of cases of severe and extreme turbulence in the interior of the zone separating two jet streams of opposite directions. In the case investigated in the paper, where two rapid and well organized currents flow in opposite directions near one another, it appears that horizontal wind shear may be the origin of the observed turbulence. (ILD)

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120. Helvey, Roger A. Observations of Stratospheric Clear-Air Turbulence and Mountain Waves over the Sierra Nevada Mountains: An Analysis of the U-2 Flights of 13-14 May 1964. California Univ., Los Angeles, Dept. of Meteorology, Final Rept 14 Jun 64-14 Sep 67, Dec 1967, 93 p. Contract AF 19(628)-4146. AD 667222.

...Data obtained from a specially-instrumented U-2 aircraft have been used to relate Clear Air Turbulence with mountain wave structure observed during two research flights in the stratosphere over the Sierra Nevada Mountains on 13 and 14 May, 1964. The several cases of severe turbulence encountered took place in regions immediately downstream of wave troughs, in areas of decreased static stability and slower wind speeds associated with the prevailing upwind tilt of the waves. An expression for the Richardson number is obtained which incorporates modifications imposed upon flow through stationary disturbances such as mountain waves. (Author)

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121. Hammerich, K.E. et al. A Case Study of Clear-Air Turbulence in the Midwest. Dept. of Met., The Penn State Univ., Final Report, 31 Mar 1967. Contract Orb 11308. DAS M(051) P415fir final.

...During flights on Apr 23-24, 1967, in the Dayton-Flint area, two airplanes sampling radioactive debris encountered moderate and severe turbulence. Because these planes also recorded

## 121. (cont.)

temperature and wind, it was possible to obtain more detailed analysis of vertical cross sections than is usually the case. All the reports of CAT occurred in a strongly baroclinic layer, in which Richardson numbers decreased during the report period. A "critical" Richardson number of 0.5 is consistent with the turbulence reports. There is strong indication that the most severe CAT occurred at the edges of the internal front.  
(Author)

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122. Hicks, John J. et al. Clear-Air Turbulence: Simultaneous Observations by Radar and Aircraft. Applied Phys. Lab., Johns Hopkins Univ., Silver Spring, Md. Science, Wash., D.C., 157 (3790):808-809, Aug 18, 1967. Fig. refs. DAS P Col.

...Ultrasensitive radars and uninstrumented jet aircraft in concert have probed regions of the clear atmosphere in search of Clear Air Turbulence. All sources of clear-air radar echoes above 6 kilometers that were probed simultaneously by the aircraft were found to be turbulent. (Author)

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123. Hodge, Mary W. Large Irregularities of Rawinsonde Ascensional Rates within 100 Nautical Miles and 3 Hours of Reported Clear Air Turbulence. Monthly Weather Rev. Vol. 95, No. 3, Mar 1967, pp 99-106, 5 refs, 7 figs, tables. DAS M(05) U587a.

...The assumption that a rawinsonde balloon system may experience large changes in its rate of ascent, as compared to the average rate for the observation, while traversing a region of Clear Air Turbulence is investigated. In a 5-day period, a well-defined region of turbulence, concentrated near a trough, progressed eastward for several successive synoptic observations. Rawinsonde ascensional rates are studied for 20 stations located within and outside this turbulent region for layers 2,000 ft to 2,500 ft thick between about 20,000 ft and 45,000 ft in altitude. Those rawinsonde observations within the turbulent region show much larger ascensional rate changes between layers, compared to the average for the observation, than do those outside the turbulent region. Furthermore, the observations showing these large variations progress eastward with time corresponding generally to the eastward motion of the turbulent region.  
(Author)

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124. Huntley, E. The Longitudinal Response of a Flexible Slender Aircraft to Random Turbulence. Aeronautical Research Council, London (England). Rept. No. ARC-R/M-3454, 1967, 44 p. AD 818005.

...The responses of a slender, supersonic aircraft flying through random turbulence have been evaluated for the cruise condition. The problem was simplified by assuming that the aircraft responds only in heave, pitch, and longitudinal bending as defined by the fundamental normal mode and by using piston-theory aerodynamics. The results show that the CG normal acceleration response is very dependent on the pitching degree of freedom but is relatively little affected by flexibility. Flexibility does have an important effect on normal acceleration at the aircraft nose, where it increases the RMS value by a factor of 2.2 but has negligible effect over the rear 70 percent of the aircraft length. It is shown that strains occurring in the fundamental mode can be correlated with CG accelerations; the factor relating them being 1.37 times the strain per G that would be measured in a steady pull-out. (Author)

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125. Kindle, Earl C. et al. A Technique to Investigate the Nature of Clear Air Turbulence. Res. Triangle Inst., Research Triangle Park, N.C. GU-242. ESD-TR-67-292. Contract No. AF 19(628)-4895, May 1967. 75 p, 5 refs. AD 816864.

...The development of a feasibility model to study the nature of Clear Air Turbulence is treated. The initial phase of the study is limited to a feasibility model for transverse perturbations in a jet stream environment. Various tests were conducted to select the most suitable numerical integration technique for use on a high resolution model. The problems of computational stability are treated in detail. The results achieved in the Phase I study support the feasibility of the overall concept. (Author)

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126. King, G.E. Civil Aircraft Airworthiness Data Recording Programme Study of Severe Turbulence Encountered by Civil Aircraft. Aeronautical Research Council, London (England), Current Papers, Rept. No. ARC-CP-974, Jun 1967, 50 p. AD 836936.

126. (cont)

...Continuous trace records of airworthiness data have been taken from a small number of aircraft in normal airline service since October 1962. The acceleration trace on a sample of records covering 3284 flying hours has been read to give peak values. The durations of the patches of turbulence have been estimated and an attempt has been made to distinguish between gust and maneuver loads. The most severe of these patches of turbulence have been studied in detail; it is found that the largest acceleration in a patch is often larger than would be predicted from Rayleigh distribution of peaks, which is the distribution normally used in spectral analysis of turbulence. (Author)

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127. Kordes, Eldon E. and Love, Betty J. Preliminary Evaluation of XB-70 Airplane Encounters with High-Altitude Turbulence. U.S. National Aeronautics and Space Administration Tech Note D-4209, Oct 1967. 21 p, fig, tables, refs, eqs. DAS 629.1308 U585tn D4209.

...Measurements of airplane response to CAT were obtained during supersonic flights of the XB-70 airplanes to an altitude of 74,000 ft over the western U.S. In general, the results for 75,757 mi of operation above 40,000 ft altitudes show that turbulence was encountered an average of 7.2% of the miles flown between 40,000 ft and 65,000 ft and an average of 33% of the miles flown above 65,000 ft with less than 1% of the turbulent areas exceeding 100 mi in length. Power spectral density estimates of the acceleration response to turbulence show that the structural modes contribute an appreciable amount to the total response. (Author)

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128. Lappe, U.O. A Preliminary Evaluation of the F-100 Rough Rider Turbulence Measurement System. Norman, Okla., Institute for Atmospheric Sciences, National Severe Storms Lab., 1967. 25 p. (U.S. National Severe Storms Lab. Tech Memo No. 36). DAS M(055) U5852re no. 36.

...Response data for elevator control inputs are used as a basis for evaluating the F-100 aircraft gust measurement systems. The procedure involves 1) use of the gust equation to evaluate responses of the aircraft maneuvered in a zero-gust (nonturbulent) environment; 2) analysis of the separate responses, with the aid of calculated frequency response

128. (cont)

functions, to isolate probable instrumental problems; and 3) estimation of overall gust velocity measurement accuracies from estimates of equivalent gust velocities obtained from measured and calculated responses. The analysis indicates that with pitch dampers off, the overall error for the F-100 gust measurement system ranges from a threshold value of about 5 ft/sec to a maximum error of about 20 ft/sec. The accuracy estimates (error per unit gust velocity) range from a few percent to about 60 percent. (Author)

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129. Mather, G.K. Flight Evaluation of an Infrared Spectrometer as a Clear Air Turbulence Detector. National Aeronautical Establishment, Ottawa (Ontario) Flight Research Section, May 1967, 84 p. AD 819533.

...A prototype of the Barnes infrared spectrometer proposed as a Clear Air Turbulence detector has undergone initial flight tests while mounted on the Canadian National Aeronautical Establishment T-33 turbulence research aircraft. Advance warning of up to 8.5 nautical miles before interception of horizontal atmospheric temperature variations were recorded. A high correlation between temperature variations and mountain waves and/or turbulence was found during the tests. The necessity of pitch stabilizing such a device against spurious aircraft attitude changes has been demonstrated. (Author)

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130. Pchelko, I.G. et al. Turbulentnost' pri iasnom nebe. [Turbulence in a Clear Sky.] Gidrometeorologicheskii Nauchno-Issledovatel'skiy Tsentr SSSR. Trudy. USAF AFSC FTD-MT-24-66-68, 1967. 19 p. IPB Files.

...The results of a systematic and statistical study of Clear Air Turbulence encountered along the main airline routes over the Soviet Union and the Socialist countries of Eastern Europe are now available in summary form. The data were collected by crews of turboprop and turbojet aircraft, generally flying at altitudes of 6-10.5 km, for four 5-day periods (9-13 Dec 1964, 10-14 Mar, 9-13 Jun, and 8-12 Sep 1965). The data were grouped into four 6-hour daily observation periods (2400-0559, 0600-1159, 1200-1759, and 1800-2359 hr Greenwich time). Some of the results of a similar study made by Colson in 1962 for the United States and those obtained in an earlier study by Soviet scientists are compared with the data of the present study.

## 130. (cont)

Major aspects of the analysis include determination of 1) the probability of encountering turbulent zones in various regions of, and altitudes above, the area covered by the study, 2) the relationship of turbulence to wind speeds and directions, vertical wind shear, Richardson number, and horizontal wind shear. Data on actual encounters with turbulence are presented for the four 5-day periods in tables and are graphically portrayed on four small-scale maps. Orig. art. has: 4 figs and 9 tables. (Author)

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131. Peckham, Cyril G. Flight-Measured Turbulence in the NATO Nations. North Atlantic Treaty Organization, AGARD Advisory Group for Aerospace Research & Development, 64 Rue De Varenne, Paris 7E France, Report 555, Feb 1967. DAS 629.1308 N864r no. 555.

...As atmospheric turbulence environment is one of the primary problem areas in military aircraft structure design, all available data on turbulence were surveyed. The major portion of the data was collected with instruments that record airspeed, altitude, and acceleration at the center of gravity plus elapsed time from takeoff; although the instruments used in the various countries differ, the pertinent information is the same. The use of the discrete gust and the continuous turbulence concepts are discussed in relation to establishing the required spectra for both approaches. All data are reported by the individual countries: Canada, Germany, Italy, France, United Kingdom, and the United States. In addition to the turbulence data, flight loads, commercial survey loads, ground loads, sinking speeds, and runway profile data were also surveyed. (Author)

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132. Penn, Samuel et al. Mesoscale Structure of the Atmosphere in Regions of Clear-Air Turbulence, Volume I. Air Force Cambridge Res. Labs., L.G. Hanscom Field, Mass. Air Force Surveys in Geophysics No. 190, Rept. No. AFCRL-67-0115, Apr 1967, 90 p. AD 654267.

...The mesoscale structure of the atmosphere in regions of Clear Air Turbulence (CAT) is investigated by means of aircraft observations of wind, temperature, and ozone obtained in the upper troposphere and the lower stratosphere. Analysis from five CAT missions are shown, including vertical cross sections

## 132. (cont)

normal to flow patterns and also detailed vertical 'soundings' of wind, temperature, and the Richardson number. A verification is obtained at intervals of 1000 ft between the occurrence of CAT and a Richardson criterion of 0.5. Over 70 percent of the 149 CAT cases are correctly specified by the criterion. (Author)

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133. Piggott, B.A.M. Atmospheric Turbulence and Aircraft Height-Keeping Accuracy. Royal Aircraft Establishment, Farnborough (England). Technical Rept. no. PAE-TR-67195, Aug 1967, 31 p. AD 823324.

...As a contribution to the study of vertical separation standards for use in air traffic control, an examination is made of the possibility of applying the spectral methods already used in gust load evaluations to the problem of determining the height-keeping errors caused by atmospheric turbulence. Although it is found that the data available on the low-frequency components of atmospheric turbulence and on the nature of the control applied by the pilot, whether human or automatic, are not sufficient to allow an accurate estimation of these errors, it is concluded that they do not make a significant contribution to the total errors experienced. It is noted, however, that certain atmospheric phenomena lie outside the scope of the theory used here. (Author)

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134. Pinus, N.Z., Reiter, E.R., Shur, G.N., and Vinnichenko, N.K. Power Spectra of Turbulence in the Free Atmosphere. Tellus 19(2):206-213 (1967). DAS M(05) T277.

...Presently known data on the spectrum distribution of turbulence energy in the free atmosphere near jet-stream level are combined from various Russian, Australian, and American sources. A comparison is made between these data. Special attention is given to the phenomenon of Clear Air Turbulence (CAT). (Authors)

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135. Plunkett, Allan B. A Radar Design for Atmospheric Turbulence Studies, Report No. P-20, Antennas and Propagation Division, Electrical Engineering Research Laboratory, The University of Texas, 1 Aug 1967, NASA CR 88494, 64 p, figs, tables, refs. DAS M(051) U585cr.

...Atmospheric turbulence can presently be measured only on the ground or by means of airplanes flying through the turbulent area. A properly designed radar system may be able to detect and analyze atmospheric turbulence from a position remote from the turbulent area. The choices of antenna, wavelength, transmitter power, receiver sensitivity, and detection methods are examined. The differences between pulse or cw and bistatic or monostatic systems are discussed. A comparison with existing radar systems used for atmospheric turbulence research is made. (Author)

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136. Priestley, J.J. Low-Level Critical Air Turbulence. Boeing Co., Wichita Kans. Airplane Div. Technical Progress Monthly Rept. No. D3-7087-16, Aug 1967, 45 p. Contr. No. AF 33(615)-3724. AD 821529.

...The contents of this report describe the low-level critical air turbulence (LO-LOCAT) program accomplishments and include milestone forecast and accomplishment schedule data as of 1 August 1967. Turbulence and meteorological test data are included. (Author)

See also:

Priestley, J.J. et al. Low-Level Critical Air Turbulence. Boeing Co., Wichita Kans. Airplane Div., Technical Progress Monthly Rept., 6 Oct-5 Nov 1967. Rept. No. D3-7087-19, Nov 1967, 76 p. Contract AF 33(615)-3724. AD 825454.

...The contents of the report describe low-level critical air turbulence (LO-LOCAT) program accomplishments and include milestone forecast and accomplishment schedule data as of 1 November 1967. (Authors)

See also:

Report of Contract AF 33(615)-3724  
by Gault, J.D. (No. 118)

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137. Reiter, Elmar R. Problem of Clear-Air Turbulence (CAT): Possible Future Developments. Astronautics & Aeronautics, N.Y., 5(8):56-58, Aug 1967. "Statement by the AIAA Technical Committee on Atmospheric Environment," DAS P Col.

...Discusses four methods that may be taken to alleviate the effects of CAT on air traffic. These are: 1) to rely on improved techniques for forecasting CAT, 2) to hope for the development of inflight remote detectors that would "see" CAT ahead of the aircraft, 3) to depend on groundbased remote CAT detectors, and 4) to think about satellite-borne CAT detectors. It is suggested that it would be highly desirable to develop sensors that reveal the mesoscale of atmospheric structure and motion, and leave the operational details to forecasting and onboard detecting of CAT. The present state of the art indicates that CAT, in a thermally stable environment, is caused by gravity waves forming under vertical wind shear. These waves break down into random isotropic turbulence. Aircraft measurements taken over Australia and the Soviet Union indicate the presence of such a "breaking" wave phenomenon. (ES)

138. Reiter, Elmar R. and Lester, P.F. The Dependence of the Richardson Number on Scale Length. Colorado State Univ., Atmospheric Science Paper No. 111, Report under Grant WBG-59 from the National Environ. Satellite Center, ESSA. Jul 1967, 43 p. DAS M(055) C719at No. 111.

...It can be shown theoretically that the Richardson number depends on the thickness  $L$  of the layer over which it is computed. The relationship has the form  $Ri \propto L^p$

where  $0 < p < 4/3$ . Experimentally, FPS-16 radar wind measurements and detailed radiosonde observations show that  $p$  may also be a function of  $L$  and that with actual wind profiles even negative values of  $p$  may be encountered.

From this study it appears that until accurate observations of the state of the atmospheric mesostructure are available, no unique correlation between  $Ri$  and Clear Air Turbulence (CAT) should be expected to exist. (Author)

139. Rosenberg, Paul et al. Clear Air Turbulence. Flight Safety Foundation, Inc., N.Y., Contract NRS-33-026-001, NASA-CR-90041, Mar 1967, 162 p, refs. N68-10364. DAS M(051) U585cr No. 90041.

...This paper is, in general, concerned with the alleviation of problems posed by flight in turbulence. Specifically, it evaluates developments in (1) forecasting and detection of air turbulence and (2) devices for indicating turbulence with particular emphasis on clear air turbulence (CAT). It also lists incidents and accidents involving turbulence, including their effects on airline operations, for 1965-66. Although the emphasis is on CAT, a broadened definition of CAT takes in almost all other types of turbulences except those actually within clouds, storms, gales, tornadoes, and hurricanes; included are studies of pilot/aircraft responses, turbulence reporting, alerting, and aircraft rerouting, engineering aspects of turbulence, and the economics of turbulence. (Author)

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140. Royal Aircraft Establishment. Civil Aircraft Airworthiness Data Recording Programme Special Events of Meteorological Origin (Jan 1965 to Dec 1965). Farnborough (England). Tech Rept. No. RAE-TR-67071, Mar 1967, 47 p, AD 823143.

...Continuous trace records of airworthiness data have been taken from a small number of aircraft in normal airline service since October 1962. Throughout the recording period the records have been searched for unusual occurrences, and each one has been studied to determine its nature and, where possible, its cause. This report describes a selection of events of meteorological origin which were found in records taken between January 1965 and December 1965. (Author)

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141. Saxton, David W. Nature and Causes of Clear Air Turbulence, Journal of Aircraft, Vol. 4, No. 4, Jul-Aug 1967. pp 356-359. 10 refs, 7 figs. DAS P Col.

...The characteristics of Clear Air Turbulence (CAT) are discussed in terms of turbulence-measuring systems and data-reduction methods. The spectral density technique of data reduction, which has largely replaced the discrete gust method, is used to illustrate the interaction between the aircraft and turbulence and to highlight the difference

141. (cont)

between undulance and turbulence. Internal gravity waves and the conditions which appear favorable for their amplification and breakdown into isotropic turbulence are discussed. Meteorological data available to diagnose and forecast CAT are evaluated and a comparison is made between conventional rawinsonde data and wind data obtained with precision missile-tracking radar. A recent XB-70A encounter with CAT is used to illustrate the challenge of the future. (Author)

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142.

Sissons, J. Analysis of Clear Air Turbulence Reports over Africa and Adjacent Ocean Areas South of Latitude 15° North. East African Common Services Organization, Nairobi. Met. Dept., Memoirs, Vol. 4, No. 3, 1967, 19 p, figs, charts, tables. DAS M(055) E13me.

...Despite the relatively small number of turbulence reports available for this study, several important features have emerged: 1) the number of cases of moderate or severe CAT over Africa south of 15°N Lat is considerably lower than had previously been imagined; 2) no appreciable diurnal variation in high-level CAT can be discerned; 3) there is a pronounced seasonal variation in turbulence which can be associated with seasonal high-level temperature and wind-flow charts; 4) areas of temperature discontinuity between cool westerlies and warm subsiding air circulating around the high-level sub-tropical high pressure zones appear to be potential areas of Clear Air Turbulence, and the frequency and intensity of the phenomenon may well be related to the temperature gradient and to the magnitude of the westerly component; 5) it appears to be extremely unlikely that frequent or widespread moderate or stronger CAT will occur below FL300; 6) instances of CAT which can be related to lee waves do occur in the vicinity of high mountains but these are not apparently as frequent as had been anticipated. (Author)

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143.

Stephens, J.J. et al. Estimating Refractive Index Spectra in Regions of Clear Air Turbulence. J. Appl. Meteorol., Vol. 6, No. 5, Oct 1967, pp 911-913, 6 refs, fig, formulae. DAS P Col.

143. (cont)

...Estimates of the spectrum of refractivity fluctuations to be expected in regions of Clear Air Turbulence are shown for scales in the inertial sub-range. Based on the complete analysis by Atlas et al., it is concluded that radar detection of Clear Air Turbulence with current technology is unlikely for all but inversion conditions. However, the present analysis can be used to provide consistent estimates for particular environmental conditions.  
(Authors)

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144.

Tchen, C.M. Turbulence in Stratified Atmosphere. Space Sciences Lab. General Electric Co., King of Prussia, Pa., Aug 1967, 25 p, 4 refs. AD 819689.

...We investigate the spectral distributions of velocity and density fluctuations in a stratified atmosphere. The equations determining the two spectra contain the following transport functions: modal transfer, production by shear, distabilization or damping by buoyancy, and acoustic diffusion. The method of cascade decomposition is applied to attack the nonlinear equations of momentum and continuity. Three cases are solved: (a) spectra by acoustic diffusion, (b) spectra by buoyancy damping, and (c) spectra by distabilizing buoyancy. The eddy viscosity, the eddy diffusivity, and the acoustic diffusion functions are derived.  
(Author)

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145.

TenBroek, H.W. et al. Low Frequency Electric Field Characteristics of Clear Air Turbulence. Honeywell, Inc. Systems & Research Div., St. Paul, Minn. Contract AF 19 (628)-5983, Final Report, Mar 15, 1966-Jul 15, 1967. Jul 15, 1967. 150 p, figs, photos, tables, eqs. DAS M(051) H772filO.

...This report covers work done by Honeywell in cooperation with Northwest Orient Airlines to investigate the low frequency electric field characteristics of CAT. A description is given of the electric field sensing system designed and constructed by Honeywell and installed in 5 Northwest Airlines 720B passenger jets. The equipment was used to gather experimental data on the correlation of electric field activity with CAT, when encountered, during the scheduled flights of these aircraft in the

145. (cont)

period between Oct 1966 and Jun 1967 (a total flight time for all 5 CAT units of approximately 4300 hrs). In this period, a total of 2320 hrs of recorded electric field data was obtained, during which 131 pilot-indicated encounters with CAT occurred. An investigation of the correlation of these encounters with the recorded data is presented, and the effects of various noise sources on system operation are discussed. (Author)

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146. Tucker, G.T. et al. Low-Level Critical Air Turbulence. Boeing Co. Wichita, Kans. Airplane Div. Tech Progress Monthly Rept, 6 Jan-5 Feb 67. Rept. No. D3-7087-10, Feb 1967, 291 p. Contract 33 (615)-3724. AD 822605.

...The contents of this report describe low-level critical air turbulence program accomplishments during the period from 6 January through 5 February 1967 and include milestone forecast and accomplishment schedule data as of 1 February 1967. Results and discussion of gust boom vibration checks are presented. Also included is a portion of the meteorological and gust data obtained thus far in the program. (Author)

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147. Tucker, G.T. et al. Low-Level Critical Air Turbulence. Boeing Co. Wichita, Kans. Airplane Div. Technical Progress-Monthly Rept, 6 Feb-5 Mar 1967. Rept. No. D3-7087-11, Mar 1967, 97 p. Contract No. AF 33(615)-3724. AD 822604.

...The contents of this report describe low-level critical air turbulence program accomplishments during the period from 6 February through 5 March 1967 and include milestone forecast and accomplishment schedule data as of 1 March 1967. Results and discussions pertaining to an evaluation of LO-LOCAT calculated gust velocities are presented; gust and meteorological test data are also included. (Author)

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148. Tucker, G.T. et al. Low-Level Critical Air Turbulence. Boeing Co., Wichita, Kans. Airplane Div. Technical Progress Monthly Rept, 6 Apr-5 May 1967. Rept. No. D3-7087-13, May 1967, 12 p. Contract AF 33 (615)-3724. AD 822603.

...The contents of this report describe low-level critical air turbulence program accomplishments during the period from 6 April through 5 May 1967 and include milestone forecast and accomplishment schedule data as of 1 May 1967. (Author)

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149. USAF, Air Weather Service. ALLCAT Conference 16-17 January, 1967. Figs, tables, maps, graphs. IPB Files.

...The objective of the ALLCAT Program is to provide fine scale, true, gust velocity measurements of continuous wavelength turbulence for all altitudes, seasons, and typical geographical areas. These turbulence data, correlated with meteorological conditions and synthesized with other data, will be used to establish valid turbulence design criteria for advanced vehicle structures, flight control systems, and human factor investigations. The turbulence data will be utilized in evaluating structural modification and life determinations of existing flight vehicles. These data will assist meteorological agencies in verifying, changing, and establishing new techniques for forecasting critical atmospheric turbulence. The turbulence data will also be useful to other technical disciplines such as physiological and psychological investigations of crew members, crew accommodations, guidance, flight instrumentation, and mission planning in operational organizations. (Author)

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1968

150. Astheimer, Robert W. Remote Detection of Clear Air Turbulence by Infrared Radiation. (Barnes Eng. Co., Stanford, Conn.) Boeing Scientific Research Labs., Seattle, Document DI-82-0710, Aug 1968. Separately-paged paper (15 p.) Figs, photos, refs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S889aum.

150. (cont)

...Describes the development of an experimental airborne scanning IR spectrometer, essentially a Fabry-Perot interferometer with a narrow field of view directed along the flight path, to investigate the applicability of radiometric measurement of IR energy emitted in appropriate spectral bands to the remote detection of Clear Air Turbulence (CAT). The physical and theoretical foundations of the problem are presented and analyzed. Initial flight tests indicated a very high correlation between turbulence and temperature changes, with CAT detection achieved at distances up to 10 mi. Instrument modifications to eliminate the unacceptable sensitivity of the prototype device to pitch are described. The redesigned instrument, "IRCAT", remained sensitive to residual pitch motions. Special filter systems designed to eliminate this source of error proved effective in later test flights; other technical improvements in additionally-planned "IRCAT" instruments are expected to optimize the IR techniques in long-range CAT detection. (JPD)

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151. Atlas, David. Clear Air Turbulence Detection Methods: A Review. Geophys. Sc. Dept., Chicago Univ. Boeing Scientific Research Labs., Seattle Document DI-82-0740, Aug 1968. Separately-paged paper (15 p. + appendix), refs, eqs. (Symposium on Clear Air Turbulence & its Detection, Seattle, Wash., Aug 14-16, 1968 Summaries of papers). DAS M51.5 S989sum.

...Discusses and evaluates various methods of Clear Air Turbulence (CAT) detection. Possible techniques include passive and active acoustics, optical stellar scintillation, microwave scintillation of radio stars and satellite beacons, IR and microwave radiometry, lidar backscatter, tropospheric bistatic radio-scatter, and ultrasensitive radar. Suggested approaches include airborne, ground-based, and even satellite-borne detectors. Ground-based ultrasensitive radars appear to be the only remote sensors which have provided definite indication of CAT. It is recommended that an airborne radar be developed with a required 20-db improvement in sensitivity for reliable CAT detection at 10 n mi. Other methods including ground based troposcatter radio techniques, the dual-pulse lidar technique of Breece et al (1966); and IR or microwave radiometer procedures show promise, if developed. An extensive bibliography is appended, together with a brief appendix on the feasibility and costs of establishing an operational radar system unit for CAT detection. (JPD)

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152. Atnip, F.K. Turbulence at Low Altitudes: Summary of the Results of LO-LOCAT Phases I and II. Boeing Scientific Research Labs., Seattle, Document DI-82-0740, Aug 1968. Separately-paged paper (3 p). (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S989sum.

...Purpose of the investigations was to obtain a rational definition of the turbulence environment below the 1000-ft altitude using statistically representative samples of turbulence data on a wide range of meteorological, topographical, seasonal, and time-of-day conditions. Turbulence wave lengths up to 7000 ft/cycle were measured. Another objective was to describe the probability distribution of RMS gust velocities; also, the analysis of the gust-velocity, spectral density functions to define their shape. The analysis employed turbulence and meteorological data acquired during the period Sep 15, 1966-Dec 20, 1967, by 4 instrumented C-131 aircraft in 1244 test flights over 340,000 mi. The flight patterns, area covered, and techniques of data acquisition with a summary of major results are presented. The probability of encountering a gust of given magnitude was found to be greater over rough terrain, at lower altitudes, and when the air is unstable. Among the findings it was determined that at absolute altitudes below 1000 feet, atmospheric turbulence is characterized by a high degree of stationarity, isotropy, and homogeneity. (JPD)

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153. Badgley, F.I. Large Scale Processes Contributing Energy to Clear Air Turbulence. Boeing Scientific Research Labs., Seattle Document DI-82-0740, Aug 1968. Separately-paged paper (5 p), refs, eqs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M 51.5 S989sum.

...Discusses: 1) the possibilities of the initiation of turbulent motions in directions other than the vertical (including implications with regard to the critical Richardson number), and 2) the manner in which the atmosphere, starting from a condition in which the Richardson number is everywhere greater than critical, can reach a condition where there are patches of lower than critical  $Ri$  (the latter calling for a decrease of static stability, or an increase in the wind shear, or both.) The first problem is analyzed from the perspective of the equation for the energy budget of eddy motions; although it is admitted that shears in the atmosphere are in fact much stronger along the vertical than other axes, it is held possible to conceive of eddy motions in a horizontal plane. It is concluded that only nongeostrophic motions can be effective in

153. (cont)

changing  $R_i$ , thus making detection of incipient Clear Air Turbulence (CAT) especially difficult. Available evidence indicates that the large scale motions preceding CAT are such as to increase both the stability and wind shear; the latter is the determining factor. (JPD)

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154.

Beard, C.I. et al. Microwave and Infrared Scattering and Absorption Related to Atmospheric Inhomogeneities. Boeing Sc. Res. Labs., Seattle, Document DI-82-0740, Aug 1968. Separately-paged paper (6 p), refs (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries of papers). DAS M51.5 S989sum.

...Describes a combined experiment to study the scattering of electromagnetic waves by atmospheric turbulence; meteorological measurements of the atmospheric structure and its statistics are taken simultaneously with the radio-wave statistics. A 10.4 GHz microwave line-of-sight atmospheric measurement technique is employed; capable of observing the statistics of the phase quadrature components of the incoherent scattered field directly; it is also sensitive to the effects of spherical wavefronts. The techniques involved and the results of the operation of the 10.4 GHz and related systems are presented; the significance of the findings with regard to the cause-and-effect relationship between the characteristics of the random refractivity field and the random signal statistics is discussed. The ability of the transmissometer measurements to isolate the particular feature of the atmosphere active as the causative agent in fluctuations in the radio signals is noted. Preliminary results of the experiments indicate that the radio signal statistics respond to atmospheric refractivity turbulence and not to wind turbulence per se although the correlation between simultaneous occurrences of the two types of turbulence is good. (JPD)

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155.

Belyayev, V.P. et al. Certain Results of Experimental Investigations of the Turbulence of the Atmosphere with Help of Radiosondes (Chapts I, II and III). FTD-MT-24-207-67, WP-AFB, Ohio. (Translated from Tsentral'naya Aerol. Observatoriya, Trudy, Central Aerol. Obs. Trans. No. 54, 1964, pp 4-52). 26 Jan 1968, 58 p. IPB Files.

## 155. (cont)

...In this article is given a description of the methodology and equipment for measuring the turbulence of the atmosphere with the help of radiosondes. Presented are the results of theoretical and experimental investigations of the methodology and also the characteristics of turbulence over Moscow, Sukhumi, and Tashkent. For the Moscow region, according to data of annual observations, we show the distribution of turbulence by height and its seasonal movement, data about the thickness of the turbulent layers, about stability of turbulent zones in time. We consider the connection of turbulence on vertical gradients of temperature and wind speed. (Author)

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156. Bhaskara Rao, N.S. et al. Correlation between Clear Air Turbulence and Temperature Gradients at Standard Isobaric Levels. Indian Journal of Meteorology & Geophysics (Quarterly) Issued by India Meteorological Dept. Vol. 19, No. 1, Jan 1968, pp 59-64. DAS M(05) I391.

...The forecasting offices which render service to turbo-prop and jet aircraft have to indicate the probable area of Clear Air Turbulence (CAT) and, if possible, the intensity of the CAT which is likely to be encountered by the aircraft. Forecasting of CAT from synoptic data is beset with many problems which have been discussed in Section 2 of this paper. There is, however, an apparent correlation between the occurrence of CAT and the increase of thermal gradient. This was statistically tested in the case of all flights for which post-flight reports were available at the Main Meteorological Office, Santa Cruz for the year 1964. The results of the test are discussed in this paper. Briefly, the results show that the method based on thermal gradients is a good guide for delineating probable areas of CAT occurrence but the method was not very sensitive for discriminating different intensities of CAT. The method has a good potentiality to be used as a forecasting tool. (Author)

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157. Bourquin, R.R. et al. Investigation of Air-Flow Velocity by Laser Backscatter. NASA TN D-4453, Wash., D.C., Apr 1968, 21 p, 7 refs, 2 figs, 3 appx., formulae. DAS 629.1308 U585tn D4453.

## 157. (cont)

...An investigation of laser-light backscatter properties from an atmosphere emphasized the effect of frequency shift. The detection scheme described is based on this effect and proved successful in the laboratory determination of flow velocity of a contaminated atmosphere. The results agree well with measurements taken with a hot wire anemometer. This investigation used a continuous wave laser radiating in the visible region. The velocity of an air stream containing a small concentration of contaminants was measured. Using this technique to detect Clear Air Turbulence would require that Mie scattering predominate in the turbulent region. This technique does not presently appear practical for airborne detection of Clear Air Turbulence considering the available laser transmitters and detectors and the uncertain knowledge of the contaminating-particle content in a turbulent region. (Author)

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158. Burnham, J. Atmospheric Turbulence and the SST: A Review in the Light of Recent Research. Royal Aircraft Establishment, Farnborough (England), Tech Rept No. RAE-TR-68096, Apr 1968, 87 p. AD 841714.

...Atmospheric turbulence problems which may be met by an SST are considered in the light of the results of high-altitude turbulence research programmes recently conducted in the U.K. and U.S.A. Disturbances have been found in the stratosphere which are of sufficient size to be significant for SST operations. Indications from results already available are that it will be possible to devise means for the avoidance of major disturbances, although it appears that turbulence in the stratosphere is less wide-spread than at lower altitudes. Up to 15% of the time, at altitudes up to 60,000 ft, may be spent in noticeable turbulence in some regions at certain times of the year. Recommendations for further work are made. (Author)

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159. Businger, J.A. On the Energy Supply of Clear Air Turbulence. Atm. Sc. Dept., Wash. Univ., Seattle. Boeing Scientific Research Labs., Seattle, Document DI-82-0740, Aug 1968. Separately-paged paper (6 p), figs, refs, eqs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, summaries of papers). DAS M51.5 S989sum.

159. (cont)

...Presents theoretical approaches to the investigation of certain atmospheric conditions under which stable atmospheric layers contain kinetic energy that may be released into turbulence, once turbulence has been triggered. The condition for instability for a perturbation of a stably-stratified atmospheric shear layer is discussed. Equations are derived to gain some insight in how much kinetic energy is available in a shear flow. It is concluded that if an atmospheric layer has the conditions that  $Ri = 1$ , then limits of 0.25 and 1 appear to indicate that a shear layer may for some time store energy available for turbulence before release. For certain specified cases of Clear Air Turbulence, the sequence of events is presented in diagram form. A turbulent energy equation is also developed; among other determinations, it is found that the maximum possible  $Ri$  number under steady homogeneous turbulent conditions is not yet known. (JPD)

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160. Clover, K.M. et al. Radar, Aircraft, and Meteorological Investigation of Clear Air Turbulence, Conference on Radar Meteorology, 13th, McGill Univ., Montreal, Aug 20-23, 1968, Proceedings, Ed. by J.S. Marshall. Boston, American Meteorological Society, 1968, pp 242-247, figs, tables, refs. DAS M01.81 R124tr 1968.

...Simultaneous studies of the lower 15 km of the atmosphere by multiwave-length radar, jet aircraft, Jimspheres, and special radiosondes have been conducted at the JAFNA radar facility at Wallops Is., Va. Below an altitude of about 6 km, most of the Clear Air Turbulence (CAT) is detected with the Wallops radars; however, the intensity of the radar echoes is not an indication of the intensity of the CAT, and not all of the clear air echoes are associated with turbulence of a scale affecting aircraft. Most radar layers correspond in height to regions of marked humidity stratification but with slight or no accompanying temperature inversions. Seldom is the reported CAT intensity greater than light at these altitudes. Above about 6 km, radar detections of clear air phenomena are less frequent but are generally associated with significant turbulence. Much of the CAT reported by the aircraft at these higher altitudes is not accompanied by radar echoes. This turbulence is usually associated with large-scale wind shear and Richardson numbers less than 1.0. Indications are that radars of sufficient sensitivity can regularly detect CAT at altitudes at least up to the tropopause; however, a radar parameter other than reflectivity must be used to differentiate between turbulent and nonturbulent phenomena. (Author)

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161. Cole, A.L. et al. Evaluation Studies of Clear Air Turbulence Detection by a Multipulse Laser Radar. Michigan Univ., Ann Arbor, Rept. No. 07830-10-F, Final Tech. Rept. Contract AF 33 (615)-3588, ARPA Order-746, Aug 1968, 126 p. AD 843777.

...A two-dimensional multipulse laser radar (PPI Laser Radar), featuring an azimuthal scan of several degrees, was designed, built, and installed in a JT-29A aircraft to evaluate the feasibility of detecting Clear Air Turbulence (CAT) by laser radar. The laser radar design was based on a theoretically possible detection of a 10 percent change of aerosol concentration in a few hundred meters at a range of 1 or 2 kilometers. CAT eddies, especially near the interface of differing air masses, should provide aerosol gradients suitable to ruby laser radar detection. Evaluation flights were conducted in the mountain wave and thunderstorm turbulence regions of Colorado and Oklahoma during the spring and early summer of 1967. The results of these flights indicate that large atmospheric aerosol concentration gradients can be detected by laser radar; however, the gradients existing in reasonably clear portions of the atmosphere were not detected and are assumed to be less than 10 percent. An advance in the state of the art will be necessary before a pulsed ruby laser can be developed into an operational CAT detector. (Author)

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162. Collis, R.T. et al. Recent Studies Related to Clear Air Turbulence: Computer Analysis and Forecasting, Turbulence, Climatology, and Lidar Observations of Atmospheric Structure that Indicate Air Motions, Stanford Res. Inst., Menlo Park, Calif. Boeing Scientific Research Labs., Seattle, Document D1-82-0740, Aug 1968, Separately-paged paper (6 p), Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16. (Summaries of papers.) DAS M51.5 S989sum)

...Summarizes the basic atmospheric conditions associated with the occurrence of Clear Air Turbulence (CAT) in relatively small areas and cites the difficulties of positive identification of the turbulence volumes of the atmosphere. It is suggested that probability analysis presents a practical approach to the problem. Initial findings show that the most reliable indicators of turbulence frequency are the vertical vector wind shear and the horizontal deformation of wind patterns. Other approaches discussed include studies of the distribution of turbulence as a function of place, altitude, and season; use of weather balloons bearing special sensor equipment; analysis of vertical wind profiles measured by FPS-16 radar, tracking rising balloons; study of satellite

## 162. (cont)

cloud photographs for possible indicators of turbulence; and application of lidar (laser radar) techniques to CAT detection including aircraft-borne, vertically-scanning lidar to recognize turbulent regions. (JPD)

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163. Colquhoun, J.R. et al. Clear Air Turbulence Analysis over the South Pacific Region for a Five-Day Period in December 1964, Central Off., Bur. of Met., Melbourne, Australia Meteorological Magazine, Melbourne, 15(3), pp 47-72, Jun 1967, received Apr 1968, figs, charts, tables, refs. PAM. DAS M(05) A938. (see #111)

...As part of the ICAO short-term high-level turbulence reporting program, data have been compiled and analyzed for flights at or above 20,000 ft. Areas of non-occurrence as well as areas of occurrence of high-level Clear Air Turbulence (CAT) were determined over the South Pacific region during a selected 5-day period in December 1964. Latitude-longitude "squares" of 2.5 degrees were used to tabulate the flight data. Flights were divided into (1) flights at or below 30,000 ft and (2) flights above 30,000 ft. Frequency distributions and percentages of CAT occurrence were computed over individual "squares," for flight elevations and also for various parameters, mainly of a meteorological nature. Six parameters - Endlich's turbulence index, vorticity, vorticity advection, "average" vertical wind shear, Richardson's number, and the Colson-Panofsky turbulence index were investigated in a study restricted to flights in the area bounded by latitudes 22.5° and 40° south and longitudes 112.5° and 160° east. Average vertical wind shear and Richardson's number gave the best results. (Author)

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164. Crooks, Walter M. et al. Project HICAT. High Altitude Clear Air Turbulence Measurements and Meteorological Correlations, Volume I. Lockheed-California Co., Burbank. Final Rept., 13 Mar 67-31 Jul 68, Rept. No. LR-21718 Vol. I, Nov 1968, 326 p. Contract F33615-67-C-1461. AD 846086. (See Vol. II - same author, title, AD 847497).

...The program objective was to determine the statistical characteristics of high-altitude CAT so as to improve structural design criteria. In addition, meteorological forecasts

164. (cont)

and analyses were to be correlated with the CAT measurements to improve CAT forecast procedures. In the extended program, 18.3 hours of high-altitude CAT were located and recorded in flights covering over 156,000 miles from bases in England, Louisiana, Maine, Panama, Florida, and California. Actual vertical, lateral, and longitudinal gust velocity time histories and power spectra were determined and analyzed. Peak counts of true-vertical gust velocity and derived-equivalent gust velocity were obtained. A practical procedure for forecasting high-altitude CAT was developed. (Author)

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165. Colson, DeVer. Meteorological Analysis of 1964-1965 ICAO Turbulence Data. U.S. Weather Bureau, Technical Memorandum WBTM TDL, No. 14, Oct 1968. 80 p, figs, tables, refs. DAS M(055) U587te No. 14.

Also his Clear Air Turbulence and Upper Level Meteorological Patterns, Boeing Scientific Research Labs., Seattle, Document D1-82-0740, Aug 1968. Separately-paged (6 p). DAS M51.5 S989sum.

.. Summaries are given of Clear Air Turbulence (CAT) data over Alaska, Canada, Greenland, North Atlantic, Caribbean, Mexico, and Central America during four 5-day periods. (Dec 1964, Mar, Jun, and Sep 1965) in ICAO worldwide, high-level turbulence collection program. Turbulence reports are summarized by intensity, altitude layer (30,000, 30,000-33,999, 34,000 ft), and location by 5° latitude-longitude squares. Meteorological analyses are presented showing probability of moderate or greater turbulence in relation to 300-mb circulation patterns, jet streams, isotach, horizontal wind shear, and contour gradients. While no sharply defined criteria are established for routine prediction of occurrence of intensity of CAT, some interesting meteorological patterns associated with unusually turbulent conditions are shown. The study illustrates the importance of large values of wind speed, wind shear, and contour gradients and also rapidly increasing values of these parameters. The study particularly shows the importance of sharply curved flow patterns around troughs and ridges. The second paper, presented at the Symposium on Clear Air Turbulence and its Detection, Seattle, 1968, presents in summary the contents of the first paper. (Author)

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166. Dutton, J.A. et al. Probabilistic Determination of Aircraft Response to Turbulence at Low Altitudes. Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson AFB, Ohio. ASD-TR-68-39, Oct 1968, 163 p, 22 refs. AD 685184.

...The theory of the distribution of maxima and exceedance statistics developed by S.O. Rice is combined with available information on atmospheric turbulence in an attempt to predict the statistics of aircraft responses. Details of the theoretical method are expounded, and the turbulence is assumed to be a Gaussian process to permit explicit calculation of the desired probability functions. Data from B-66 and F-106 gust investigations are combined with theoretical results to compute the statistics of maxima and exceedances for a variety of special cases.

Methods to utilize the actual distribution of turbulence are investigated. Straightforward approaches will probably not be practical unless the turbulence possesses a nearly Gaussian joint distribution for the velocity and the first two derivatives. (Author)

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167. Dutton, John A. Probabilistic Structure of Clear Air Turbulence: Some Observational Results and Implications. Met. Dept., Penn. State Univ., Boeing Scientific Research Labs., Seattle, Document DL-82-0740, Aug 1968. Separately-paged paper (13 p). Refs, eqs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries of papers). DAS M51.5 S989sum.

...Turbulence is described as a physically-generated random process. Improved models of the probabilistic structure of turbulent motion in the atmosphere must be based on a better understanding of its statistical characteristics; these characteristics are discussed in relation to Gaussian processes. A review of relevant statistical concepts is presented, including peak and exceedance statistics. The time history data for various parameters of turbulence derived from several observation periods are examined with respect to the distribution of the velocity components; a hypothesis consistent with this distribution is developed. It is concluded that the observed turbulence is patchy and the velocities distributed locally in a Gaussian manner. (JPD)

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168. Endlich, Roy M. et al. The Turbulence Climatology of the United States between 20,000 and 45,000 Feet Estimated from Aircraft Reports and Meteorological Data. Stanford Res. Inst. Menlo Park, Calif. Final Report, 10 May 65-9 Jun 68, Jun 1968, 71 p. Contract No. AF 19(628)-5173. AD 672988.

...The climatology of Clear Air Turbulence is defined herein as the likelihood that an aircraft or missile will encounter turbulent air at a given locality, altitude, and time of year. Turbulence data of three types were used in this study. These include observations by instrumented research aircraft, balloon tracks measured by FPS-16 radar, and turbulence reports made by pilots. The FPS-16 tracks of rising jimsphere and rose balloons were obtained during studies of detailed wind profiles. We investigated their potential value in identifying turbulent layers. The subjective turbulence reports from pilots collected during special five-day reporting periods comprise by far the largest volume of data available. Meteorological conditions for these periods were analyzed by computer from standard rawinsonde data and were correlated with the turbulence reports. Optimum multiple regression equations between turbulence frequency and the mean and standard deviation of the vertical vector wind shear were obtained. In summer a different regression equation was found than in other seasons. (Author)

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169. Falcone, Francesco and Nania, Abele. Preliminari per uno studio regionale della turbolenza in atmosfera serena. [Preliminaries for a Regional Study of Turbulence in a Quiet Atmosphere.] Rivista di Meteorologia Aeronautica, Rome, 28(4):39-48, Oct/Dec 1968. Figs, charts, tables, refs, eqs. Italian, French and English summaries p 39. DAS M(05) R625.

In Italian

...The authors present a procedure for analyzing on a regional scale over Puglia, the relationship between Clear Air Turbulence (CAT) and the Richardson number and wind velocity and direction at the flight level of an aircraft. The contents include the following: a nomogram for calculating the Richardson number for thicknesses of 500 m above and below flight level; the relationship between observed CAT over Puglia and different values of the Richardson number presented in a frequency table; and the application of the relationship between CAT and Richardson in CAT prediction for Puglia. (Authors)

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170. Flint, E.F. Clear Air Turbulence: An Aviation Hazard, Naval Research Reviews, Wash., D.C., Vol. 21, No. 7, Jul 1968, pp 1-6, figs, photos. DAS P Col.

...The author summarizes briefly various approaches used to develop a workable Clear Air Turbulence (CAT) detection system, such as laser, radar, microwaves, etc., and points out their inadequacies. This is followed by a brief account of the development of the Infrared Identification System at Autonetics. The infrared approach is based on the evidence that turbulence in clear air, or in cirrostratus clouds is associated with thermal density or ice crystal concentration changes. The latest model of the Infrared Identification System (IDIA-5X3A) is described briefly and its operation is illustrated. (ILD)

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171. Flint, E.F. Infrared Clear Air Turbulence Detection and Warning System. Autonetics Div., No. Amer. Rockwell Corp. Boeing Scientific Research Labs., Seattle, Document DL-82-0740, Aug 1968. Separately-paged paper (46 p), figs (1 fold laid in), photos, tables. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries of papers). DAS M51.5 S989sum.

...Describes the development, design, testing, and capabilities of an operational, Clear Air Turbulence (CAT) detection and warning system using a passive, infrared radiometer to sense atmospheric turbulence, both in clear air and in Cs, at distances up to 32 miles ahead of the aircraft. The various technical approaches to CAT detection are outlined and the advantages of the system presented are discussed. A detailed technical description of the sensor, its components, data acquisition, processing and display systems, physical specifications, and mounting is provided. The flight test program results are summarized. (JPD)

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172. Cannon, Millard T. et al. Contract End Item Detail Specification. Part I. Performance/Design and Qualification Requirements, Air Turbulence Measuring Set, AN/AMQ-20 and ( ). Nov 1968, 39 p, Contract No. F19628-68-C-0229. AD 846984.

...The Air Turbulence Measuring Set (ATMS) is used to sense the longitudinal components of turbulence gust from a moving aircraft and to convert these turbulent gusts into an output

172. (cont)

voltage proportional to the gust intensity. The ATMS senses atmospheric turbulence by means of a pitot-static tube mounted in an unobstructed airstream on an aircraft. Pressure variations incident upon the pitot-static tube are converted by a differential pressure transducer into an electrical signal. The signals are then processed in an analog computer and recordable output signal is provided. The ATMS also consists of a control panel from which all system functions are controlled, and from which the system output can be monitored. (Author)

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173. George, J.J. The Prediction of Clear Air Turbulence, Eastern Airlines, Atlanta, Ga., Jun 1968, 76 p, 78 refs, 30 figs, 7 tables. DAS MO9.329 G348pr.

...Cites examples of Clear Air Turbulence (CAT), notes incomplete understanding of its causes, warns against over-forecasting, and describes and illustrates the generally employed techniques of forecasting CAT. Basic types of CAT are listed as convective, wind shear, low level orographic, and mountain wave (Harrison). A general classification of the numerous forecast predictors is provided. The discussion of each separate predictor within each classification is limited by the degree of usefulness to the forecaster. Forecast parameters include the wind field, its relation to jet streams, and other wind relations; the temperature field including stability; synoptic patterns; combination parameters, and miscellaneous factors, including mountain waves, significance of edge of cloud cover, upper troposphere configurations, extrapolation of current CAT reports, and geographic associations. CAT over land occurs primarily in winter and spring months; over water, in winter and fall. Dimensions, duration, and percentage of occurrences of CAT by month are cited. Special conditions over ocean are also discussed. Specific procedures are suggested for preparing CAT predictions; in CAT forecasting to date, however, a subjective judgment is an important element. (JPD)

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174. Griffin, C.R. Jr. and Lagrone, A.H. The Correlation of the Scattering Cross-Sections of the Disturbed Index of Refraction and the Acceleration Increment of a Conventional Aircraft Due to Clear Air Turbulence, Tex. U., Austin, Antennas and Propagation Lab., Rept. No. P-28, May 1968, 28 p. Contract NSF-GA-772. AD 675647.

174. (cont)

...The theoretical relationship between the effective radar backscattering cross-section for regions of atmospheric turbulence and the mechanical energy of the turbulence is developed along the lines of the existing theory. The cross-section formula is developed in terms of two parameters, the mean gradient of refractive index fluctuations in turbulence, and mean squared velocity fluctuations. Next, the response of a conventional aircraft, in terms of load factor, to vertical components of velocity is determined and the substitution of parameters, which is effected, results in an expression for turbulence scattering cross-section in terms of mean squared load factors measurable from an aircraft, and refractive index gradient, also measurable from an aircraft. A method is thus obtained for verifying the theory of homogeneous turbulence and associated scattering theory by simultaneous measurement of radar cross-section parameters from an aircraft in the turbulence and by a ground-based radar set. (Author)

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175. Hardy, Kenneth R. Radar Investigation of Clear-Air Turbulence. USAF Cambridge Res. Labs., Bedford, Mass. OAR Research Applications Conference, 3rd, Arlington, Va., Mar 21, 1968, Proceedings. [1968] Vol. 1:Sec. D (16 p), figs, photos, refs, eqs. DAS 629.43 U585loar OAR 68-001. AD 666800.

...Ultra-sensitive radars regularly detect echoes in the clear atmosphere. The echoes are caused by insects and birds or by scattering from regions of the atmosphere where the fluctuations in refractive index are large. Thin elevated layers and the tropopause have been detected by virtue of scattering from refractive index variations in clear air. The relationship between these clear-air radar echoes and turbulence is discussed. The radar experiments during which aircraft probed the atmosphere in search of Clear Air Turbulence are described. It has been found that all regions of clear-air radar echoes above 6 km probed with the aircraft were turbulent. (Author)

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176. Hardy, Kenneth R. Recent Advances in the Radar Detection of Clear Air Turbulence at Wallops Island, Va., Boeing Scientific Research Labs., Seattle, Document D1-32-0740, Aug 1968. Separately-paged paper (4 p), Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, (Summaries of papers). DAS M51.5 S989sum.

176. (cont)

...Evaluates the potential of radar as a sensor for Clear Air Turbulence (CAT) with special reference to the December 1967 through March 1968 Wallops Island multiwave investigations of the lower 15 km of the atmosphere in association with jet aircraft, Jimspheres, and special radiosondes. The physical parameters of CAT detection are described and analyzed, noting three conditions essential to the development of turbulence; increasing wind-shear stresses; flow irregularity; and a stable initial lapse rate. It is suggested that the development of more sensitive radars than those at Wallops Island should permit significant CAT detection up to altitudes of at least 15 km. (JPD)

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177. Katz, Isadore. Probing the Optically Clear Atmosphere with Radar: A Review. Applied Phys. Lab., Johns Hopkins Univ., Silver Spring, Md., Boeing Scientific Research Labs., Seattle, Document D1-82-0740, Aug 1968. Separately-paged paper (4 p). Figs, photos, refs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S989sum.

...Assesses the capabilities on high power radars for viewing the optically-clear atmosphere in motion within 20,000 ft of the Earth's surface. Layer-type echoes, echoes from convective cells, and instrumented aircraft flights into echo regions are discussed. Tests conducted at Wallops Is. (Konrad and Randall, 1966) to pinpoint radar and atmospheric measurements for a check of the theoretical relationship are described. It is concluded that high power radar may be used very effectively to probe the troposphere. (JPD)

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178. Lawrence, J.D., Jr. et al. Laser Backscatter Correlation with Turbulent Regions of the Atmosphere. NASA, Langley Research Center. Boeing Scientific Research Labs., Seattle, Document D1-82-0740, Aug 1968. Separately-paged paper (7 p). Figs, refs, eqs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries of papers.) DAS M51.5 S989sum.

...Describes a program at Langley Research Center, Va. to investigate the correlation between local aerosol concentrations as observed by a ground-based laser radar and turbulence as experienced by an aircraft. The scattering of ruby laser

178. (cont.)

radiation in the atmosphere is expressed by an equation whose solution is interpreted in terms of the presence of sharp discontinuities at various altitudes, indicating the presence of local aerosol concentrations. The equipment employed in the system is described and the experimental results in conjunction with a T-33 type jet aircraft are presented and evaluated. Significant correlations of turbulence detection were determined. (JPD)

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179. Long, Robert R. Vertical Velocities in Clear Air Turbulence. Mechanics Dept., Johns Hopkins Univ., Baltimore. Boeing Scientific Research Labs., Seattle, Document D1-82-0740, Aug 1968. Separately-paged paper (5 p). (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M 51.5 S939sum.

Also: Long, Robert R. Vertical Velocities in Clear Air Turbulence. Boeing Scientific Research Labs., Seattle, Wash. Flight Sciences Lab. Rept. No. D1-82-0738, May 1968, 21 p. AD 683425.

...Presents an evaluation of significant elements in the occurrence of Clear Air Turbulence (CAT) with special reference to the probable sources of energy for the disturbed motion, including available potential energy in a stably stratified atmosphere and the energy of mean motion. Smoothing of variations of mean velocity is stated to release kinetic energy available for the atmospheric disturbances. CAT in mountain waves is discussed and various explanations of the phenomenon are offered. It is considered that, if the highest atmospheric stream velocities (as in the jet stream) attain 200 mph, a maximum vertical velocity in CAT associated with mountains can be 75 mph. Turbulence in shearing currents is discussed as the second basic source of CAT; the importance of the Richardson number in relation to the interplay of shear and stability is emphasized. The essential terms of a total energy equation as a basis for a theory of turbulence in a stable shearing current are presented and analyzed with reference to momentum and heat transfer and other factors in quantitative estimates of the characteristics of wave disturbances, turbulence, and mean distributions of velocity and density. (JPD)

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180. Loving, Neal V. Technical and Meteorological Planning to Meet the ALLCAT Program Objectives. Air Force Flight Dynamics Lab., Wright Patterson AFB, Ohio. Boeing Scientific Research Labs., Seattle, Document DL-82-0740. Aug 1968. Separately-paged paper (12 p), figs, (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries on papers). DAS M51.5 S989sum.

...The objective of the Critical Atmospheric Turbulence (ALLCAT) Program assigned to the Structures Div., of the Air Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio is obtaining a statistically adequate and meteorologically-correlated sample of atmospheric turbulence data required to establish gust design criteria for aerospace vehicles. A secondary aim is to provide data to verify old, or establish new, Clear Air Turbulence (CAT) forecasting techniques. The major structural design data requirements are presented with emphasis on the definition of variance as a function of altitude and local meteorological and geophysical parameters. The six ALLCAT Program projects to measure atmospheric turbulence from the Earth's surface to an altitude of 200,000 ft are described. They include takeoff and landing, and very low, low, medium, high, and very high altitude CAT research tests, using specially-instrumented aircraft. Associated activities in meteorological planning and correlation, ALLCAT data processing and analysis flight planning and costs are discussed with reference to the program's objectives. (JPD)

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181. Mather, G.K. Clear Air Turbulence Research Activities at the National Aeronautical Establishment. (Natl. Aeronautical Estab., Natl. Res. Council of Canada, Ottawa). Boeing Scientific Research Labs., Seattle, Document DL-82-0740, Aug 1968. Separately-paged paper (7 p), refs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S989sum.

...Discusses results of two cooperative field experiments of the National Aeronautical Establishment's T-33 research aircraft in measuring mountain waves and Clear Air Turbulence; (CAT) at Moffett Field, Calif. and at Boulder, Colo. in 1967. The T-33 is equipped to measure longitudinal, lateral, and vertical components of atmospheric turbulence; a description of the instrumentation system and its capabilities is provided including dynamic checks on performance carried out before and after each CAT measurement program. The methods employed in data analysis by analog computer are summarized. The assessment of the results of CAT measurement by the systems described includes

## 181. (cont)

power spectral analysis and other spectral parameters. Richardson numbers were computed and compared as derived from several aircraft soundings. Tests involving remote thermal detection techniques, and their preliminary results, are also discussed. It is concluded that an IR instrument capable of detecting thermal gradients ahead of an aircraft can be built, but extensive testing will be required to demonstrate its reliability as a CAT warning device. (JPD)

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182. Mather, G.K. Evaluation of an Infrared Spectrometer as a Clear Air Turbulence Detector, Pt. 2. Natl. Res. Council of Canada, Ottawa. Symposium on Remote Sensing of Environment, 5th, Univ. of Mich., Ann Arbor, Apr 16-18, 1968, Proceedings, Sep 1968, pp 599-608, figs, photos, refs. (For Pt. 1, Weiss, M.) DAS M(051) S989p.

...Summarizes significant details of tests made at Edmonton, Alberta (Can.), Nov 22-Dec 7, 1966, and at Moffett Naval Air Station, Calif., Feb 1-Mar 3, 1967 to investigate the potentials of infrared techniques for remote sensing of Clear Air Turbulence (CAT). Also, reports on initial experience with an improved infrared detector currently undergoing flight trials. Capabilities of the N.A.E. T-33 turbulence research aircraft are outlined and the test results from the infrared spectrometer are presented (in graph form) and interpreted. A condensed summary of the results, with respect to temperature variations recorded, presence of waves and turbulence, and advance detection times (in seconds), is provided. Present and future infrared sensor test flight programs and their objectives are outlined. The correlation between moderate to severe CAT encounters and temperature change is useful, and results from the U-2 HICAT program suggest an even stronger correlation in the stratosphere. (JPD)

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183. Minervin, V. Ye. Turbulence in the Lower Layer of the Atmosphere and in Low-Level Clouds, Tsentral'Naya Aerologicheskaya Observatoriya. Trudy, 1966, USAF, AFSC, FTD Trans., FTD-MT-24-352-68, Wright-Patterson AFB, 1968, 25 p. IPB Files MF. AD 685962

...Contains the results of the low-level flights made by aircraft of the Central Aerological Observatory during the 1962-

183. (cont)

1963 period. 624 observations were taken; of these, 106 vertical profiles of the coefficient of turbulent exchange were constructed. Several graphs of turbulence in relation to lapse rate, specific humidity, and coefficient of turbulent exchange are included. (DLB)

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184. Mitchell, Finis A. and Prophet, David T. Meteorological Analysis of Clear Air Turbulence in the Stratosphere. Lockheed-California Co., Burbank. Boeing Scientific Research Labs., Seattle, Document DL-82-0740, Aug 1968, Separately-paged paper (8 p), figs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries of papers). DAS M51.5 S989sum.

...In Part 1, a detailed meteorological analysis of several high altitude Clear Air Turbulence (HICAT) flights is presented. The evaluation of the high-altitude forecast procedures during field operations for the HICAT project indicates that the most effective method is to analyze the horizontal and vertical temperature profiles. The intensity of turbulence in the lower stratosphere is shown to be normally associated with the magnitude of vertical and horizontal temperature gradients. Based on an analysis of HICAT flights, the relationships between temperature gradients and turbulence, (presented in tabular form for small, medium, and large temperature gradients) is suggested as an aid in forecasting turbulence intensity. In Part 2, an interpretation of radiosonde temperature profiles is presented in terms of wave motion in the stratosphere. It is demonstrated by mathematical and physical analysis how a simple sine wave disturbance could provide a physical explanation for the apparent relationships of Clear Air Turbulence and large changes in vertical temperature gradients on the one hand, and of smooth air with constant, or only slightly varying, vertical temperature gradients on the other. A mathematical expression is derived permitting calculation of values for RMS vertical acceleration directly from the temperature profile. (JPD)

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185. O'Hara, F. et al. The Atmospheric Environment and Aircraft - Now and the Future. Royal Aircraft Establishment, Farnborough (England). Tech Memo Rept. No. RAE-TN-AERO-1067, Jul 1968, 52 p. AD 848696.

...A survey is made of the effects on aircraft of the main atmospheric factors and of the way they are dealt with in design and operation at the present time. Possible developments in the

185. (cont)

pattern of the relationship of aircraft to the atmospheric environment are discussed, in the light of expected advances like operational VTOL and orbital-type flight, reliable weather forecasting, effective turbulence avoidance and gust alleviation systems. These developments should all be conducive to safer and more comfortable flight. Further benefits would accrue from weather control in the vicinity of airfields, of which there are some prospects. Improvement in en-route operation through weather control appears less probable, and the prospects of smoothing turbulence ahead of the aircraft are speculated on. (Author)

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186. Oklahoma State Univ. Stillwater School of Electrical Engineering. A Center for the Description of Environmental Conditions - Weather Phenomena. Annual Rept. No. OSU-WP-69-1-4, Oct 1968, 90 p. Contract DAABO7-68-C-0083. AD 691122.

...The program was initiated with a three-phased effort: 1) the development and use of instrumentation to measure the electromagnetic signature of certain weather phenomena (Clear Air Turbulence, thunderstorms, tornadoes) in airborne and ground-based laboratories; 2) the investigation of pattern recognition in the total data acquisition program (sferics, severe weather, existing meteorological information); the data analysis and application to identify indicators for probability of specific phenomena; to determine possible trigger mechanisms which induce the phenomena; and to define techniques for possible modification-abatement, diversion, or intensification of the phenomena; 3) the development of one or more simple airborne instrument packages which can be put in any aircraft for short term measurement of the severity of weather immediately ahead. (Author)

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187. Panofsky, H.A. et al. Case Studies of the Distribution of CAT in the Troposphere and Stratosphere, J. Appl. Meteorol., Vol. 7, No. 3, Jun 1968, pp 384-389. DAS M(05) J86j0a.

...Two separate case studies of Clear Air Turbulence are presented, one in the stratosphere over the Rocky Mountains, the other in the upper troposphere over the midwestern plains. The mechanism in both situations appears to be similar. CAT occurs in strongly baroclinic zones with strong vertical wind shears and low Richardson numbers. There is a tendency for the most severe turbulence to be located at the edges of the baroclinic zones. (Author)

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188. Pao, Yih-Ho (chairman). Symposium on Clear Air Turbulence and its Detection. Boeing Scientific Res. Lab., Document DL-82-0740, Seattle, Wash., 14-16 Aug 1968. DAS M51.5 S989sum.

...This symposium presents and reviews the recent developments in CAT, especially on: 1) theories and measurements concerning the origin and structure of CAT, 2) methods of forecasting CAT, and 3) methods for the remote detection of CAT. Special emphasis is placed on CAT in the upper troposphere and stratosphere. (Fr. author's abst.)

For individual papers appearing in the Proceedings, see Item Numbers

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189. Pchelko, I.G. et al. Turbulence in a Clear Sky. Foreign Technology Div., Wright-Patterson AFB, Ohio. Rept. No. FTD-MT-24-66-68, Jun 1968, 24 p. AD 679685.

...The results of a systematic and statistical study of Clear Air Turbulence encountered along the main airline routes over the Soviet Union and the socialist countries of eastern Europe are now available in summary form. The data were collected by crews of turboprop and turbojet aircraft, generally flying at altitudes of 6-10.5 km for four 5-day periods (9-13 Dec 1964, 10-14 Mar, 9-13 Jun, and 8-12 Sep 1965). The data were grouped into four 6-hour daily observation periods (2400-0559, 0600-1159, 1200-1759, and 1800-2359 hr Greenwich time). Some of the results of a similar study made by Colson in 1962 for the United States, and those obtained in an earlier study by Soviet scientists, are compared with the data of the present study. Major aspects of the analysis include determination of (1) the probability of encountering turbulent zones in various regions of and altitudes above the area covered by the study, and (2) the relationship of turbulence to wind speeds and directions, vertical wind shear, Richardson number, and horizontal wind shear. Data on actual encounters with turbulence are presented for the four 5-day periods in tables and are graphically portrayed on four small-scale maps. (Author)

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190. Pedeau, R. Contribution A L'Etude De La Turbulence en Air Clair [Contributions to the Study of Clear Air Turbulence], Ministere des Transports, Direction de la Meteorologie Nationale, Monographies de La Meteorologie Nationale, No. 68, Paris, Dec 1968, 143 p. DAS M(055) F815mo.

In French

...This statistical study is well documented with 30 figures and 88 tables. Many of the figures are maps showing synoptic situations involving CAT. Tables include frequency of occurrence of CAT at various altitudes and locations, also, includes CAT in vicinity of tropopause. (ALS)

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191. Priestley, J.J. et al. Low-Level Critical Air Turbulence. Boeing Co., Wichita, Kans. Airplane Div., Monthly Tech. Progress Rept., 6 Dec 67-5 Jan 68, Rept. No. D3-7087-21, Jan 1968, 46 p. Contract No. AF 33(615)-3724. AD 830072.

...The contents of this report describe low-level critical air turbulence program accomplishments during the period from 6 Dec 1967 through 5 Jan 1968 and include milestone forecast and accomplishment schedule data as of 1 Jan 1968. (Author)

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192. Reed, Richard J. Study of the Relation of Clear Air Turbulence to the Mesoscale Structure of the Jet Stream Region. Atm. Sc. Dept., Wash. Univ., Seattle. Boeing Scientific Research Lab., Seattle, Document D1-82-0740, Aug 1968. Separately-paged paper (6 p), fig, refs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S989sum.

...With regard to the occurrence of a widespread persistent area of Clear Air Turbulence (CAT) observed over a 500-km distance between New York City and Gordonsville, Va. on April 18, 1965, the relation of the CAT to the mesoscale structure of the jet stream, previously found by Penn and Fisinski (1967), is confirmed and reviewed, and the origin of the mesoscale structure is determined by tracing air trajectories. The meteorological synoptic setting is described and the principal features of the mesoscale structure and its evolution are presented and analyzed. It is concluded among other findings that CAT can rapidly alter the atmospheric structure in the jet-stream region, producing sharp features as heat and momentum are rapidly redistributed in

## 192. (cont)

thin layers. Mesoscale features may assist in locating CAT, but do not necessarily have predictive value, although they may serve as initiators of further turbulence, once small-scale features have been produced. (JPD)

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193. Regula, H. Luftaufnahmen von Turbulenzcirren in einem Hohentrog. [Aerial Photos of Cirrus Turbulence in an Upper Trough], Offenbach am Main, Meteorologische Rundschau, Berlin, 21(5):155-156, Sep/Oct 1968, figs, refs. German and English summaries p 155. DAS M(05) M587.

In German

...Cirrus clouds are often an indication of the presence of Clear Air Turbulence. A photograph of Ci turbulence obtained from an aircraft near Newfoundland on March 31, 1967, and a chart showing the topography of the 500-mb surface at 1200 GMT for the same date are presented. Turbulence occurred in the vicinity of the clouds and a light disturbance was perceived at a distance of 60 n mi. Turbulence was intense at a height of 10,000 m for a distance of 40 n mi, but it was light during flight above the Ci clouds. The turbulence was associated apparently with a trough aloft above Newfoundland. The clouds were in the longitudinal axis of the trough. (ILD)

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194. Reiter, Elmar R. Nature of Clear Air Turbulence: A Review. Atm. Sc. Dept., Colo. State Univ., Ft. Collins. Boeing Scientific Res. Labs., Seattle, Document D1-82-0740, Aug 1968. Separately-paged paper (12 p), refs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S989sum.

...Clear Air Turbulence (CAT) is defined as comprising "all turbulence in the free atmosphere of interest in aerospace operations that is not in, or adjacent to, visible convective activity. This includes turbulence found in cirrus clouds not in, or adjacent to, visible convective activity. (1966 Resolution, Natl. Comm. for Clear Air Turbulence)." The meteorological aspects of CAT are discussed in relation to the problem of CAT detection, forecasting, and forewarning. The dimensions of CAT, the conditions and locations of its occurrence, as theoretically derived and actually observed; and the nature of the phenomenon are discussed, with special reference to the inertial subrange of turbulence and to the

194. (cont)

conditions lying beyond this subrange in which the redistribution, generation, and/or dissipation of kinetic energy by various physical processes became important. "Models" of CAT formation are evaluated. (JPD)

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195. Reiter, Elmar R. Recent Advances in the Study of Clear-Air Turbulence (CAT). Navy Wea. Res. Facility, NWRP 15-0468-136, 17 Apr 1968, 28 p, 39 refs. IPB Files.

...This paper summarizes the contemporary state of CAT research. Among the features noted are that CAT is essentially a small-scale phenomenon with a horizontal extent which is usually 40 mi or less. Its occurrence and intensity depend upon the degree of instability of the atmosphere and the presence of a "small perturbation" to act as a catalyst. A physical CAT model is presented which explains many of the characteristic features that have been observed, and effects to be expected by aircraft in the future. This model has exhibited promising forecasting applications. (Author)

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196. Scorer, R.S. Mechanisms of Clear Air Turbulence. Imperial Coll., London. Boeing Scientific Res. Labs., Seattle, Document DL-82-0740, Aug 1968. Separately-paged paper (22 p), figs, refs, eqs. (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968. Summaries of papers). DAS M51.5 S989sum.

...Presents a theoretical discussion of the mechanisms which produce the vorticity held responsible for Clear Air Turbulence (CAT). It is essential to an understanding of CAT to discover where those mechanisms can operate which will continuously change the vorticity structure of the air as it passes through. The discussion considers the following: 1) changes in the velocity profile, accompanied by changes in the temperature profile of the air (an increased static stability may accompany the production of greater shear); 2) mechanisms for changing the vorticity-analysis of the relevant equations developed leads to the conclusion, among other findings, that the greatest decreases in  $Ri$  occur where air with forward shear is decelerated and flows upslope, or where air with backward shear (negative  $n$ ) is decelerated while flowing downslope; 3) centrifugal instability, where acceleration due to curvature can produce important effects when the static instability is small and the shear

196. (cont)

already large; and 4) thin shear layers produced by larger scale centrifugal instability-cellular overturning will produce in jet streams both the velocity and temperature gradients required for the mechanisms discussed above to become operative in creating CAT. The discussion concludes with comments on the form of CAT, with special reference to billows and billow motion, and on other possible forms of CAT. (JPD)

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197. Sharma, Om P. et al. Molecular Backscatter of Laser Radiation from Turbulent Air. California Univ., San Diego La Jolla. Jul 1968, 5 p. Contract F44620-68-C-0010. AD 682115.

...The backscatter of laser pulses transmitted from the ground has been previously used to determine density profiles of air. For detection of Clear Air Turbulence (CAT) produced by random temperature fluctuations, theoretical estimates were reported for turbulent backscatter of laser light; correlations of laser backscatter with turbulent regions of the atmosphere have also been reported. In this note, theoretical estimates for measurements of density and velocity fluctuations associated with turbulent molecular backscatter of airborne laser sources are discussed. The analysis includes detailed consideration of molecular backscatter. The effect of unusual aerosol concentrations is, of course, easily calculated once the nature of the aerosol is specified. However, this problem has nothing to do with our analysis. The occurrence of sizeable aerosol concentrations can only simplify the detection of CAT. Evidently, deviations from normal backscatter may indicate CAT. (Author)

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198. United States Air Force, Air Force Systems Command. DOD National Program for Clear Air Turbulence, (NCAT) Development Plan; Advanced Development Program, DOD Program Element 034 XXXF, 17 May 1968, and DOD Measurements and Observations Program, 30 Jun 1968. IPB Files.

...Because of the concern of various governmental agencies on the level of coordination of the efforts in the Clear Air Turbulence (CAT) area, the National Committee for Clear Air Turbulence (NCCAT) was established in February 1966 to investigate the research and development of airborne CAT detection devices, CAT forecasting, basic CAT research, and

198. (cont)

CAT data collection. This Committee concluded in a report dated December 1966 that the solution of the CAT problem is in the national interest and there is a need for a coordinated national effort leading to a common solution. The NCCAT Committee recommended that DOD assume primary responsibility for, and coordination of government efforts in the area of measurements and observations of CAT, including remote detection, and act as the executive agent for the operation of the National CAT Data Collection Project. These responsibilities were delegated to the Air Force by DDR&E. (Author)

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199. Weiss, M. Evaluation of an Infrared Spectrometer as a Clear Air Turbulence Detector, Pt. 1. Barnes Engr. Co., Stanford, Conn., Symposium on Remote Sensing of Environment, 5th, Univ. of Mich., Ann Arbor, Apr 16-18, 1968, Proceedings. Ann Arbor, Sep 1968, pp 587-597, figs, photos, refs. DAS M(051) S989p.

Part 2 of this report - see Mather, G.K.

...This paper briefly surveys a variety of techniques that were tried for the detection of Clear Air Turbulence (CAT) including microwaves, lasers, electric fields, light beams, and infrared, etc., and then discusses in detail the infrared method. The primary objective is to provide a way of remotely detecting CAT and to obtain adequate advance warning of the presence of CAT so as to prevent encounters with it. Indications are that of the variety of techniques explored, infrared appears to be one of the most promising. The infrared instrument and its principle of operation are described. Data traces are presented of the actual flight records that show the pattern of the instrument response for instances of detection of mountain waves, CAT, and the response of the instrument as it approaches the side of a mountain as a known boundary having a well-defined temperature discontinuity. An improved instrument was developed based on the results of the above flight test results. This instrument is presently under test. The basic improvements include much simpler optical sampling, precise pitch stabilization of the line of sight, and a mechanical design configuration and size more suitable for use in operational rather than research-oriented aircraft. (Author)

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200. Vinnichenko, N.K. Recent Investigations of Clear Air Turbulence in the USSR. Central Aerolog. Obs. Boeing Scientific Research Labs., Seattle, Document D1-82-0740, Aug 1968. Separately-paged paper (6 p). (Symposium on Clear Air Turbulence and its Detection, Seattle, Wash., Aug 14-16, 1968, Summaries of papers). DAS M51.5 S989sum.

...States the need for prediction and detection of Clear Air Turbulence (CAT), especially for supersonic transport at high altitudes; review current Soviet methods of investigating CAT at various altitudes using meteorological towers, helicopters, balloons, aircraft, and radar stations; and describes the types of standard airborne equipment employed in CAT research. Results of investigations suggest the presence of at least 4 types of energy spectra, whose distribution and characteristics are described. Frequent conditions of severe turbulence noted over mountains, where effective vertical velocities up to 10-12 m/sec have been determined and turbulent zones are retained over periods of several hours. Future research will require the combined use of aircraft, special ground based radar, and aerological techniques. At present there is a lack of any theory describing the conditions of meso- and micro-scale instability of 3-dimensional flow in the free atmosphere. (JPD)

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201. Wilson, H.P. On Forecasting Clear Air Turbulence, Met. Branch, Canadian Dept. of Transport, TEC 672, 6 May 1968, Toronto. 9 p, 5 refs, 5 eqs. DAS M09.329 W748on.

...Presents a discussion of forecasting Clear Air Turbulence, based partly on observation but mainly on Clodman's theory on the subject. (Author)

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1969

202. Brylev, C.B. Radar Probing of the Troposphere under Clear Sky Conditions. Leningrad. Glavnaya Geofizicheskaya Observatoriya. Trudy (Russian) 1968. FTD-MT-24-160-69, 9 Sep 1969, 28 p. Orig. art. has: 7 figs, 1 table, and 29 formulas. IPB Files.

202. (cont)

...The author discusses the nature and the origins of radar echoes in clear air in the absence of hydrometeors. Four different types are defined: 1) discrete-coherent echo, 2) reflections from inversion layers, 3) reflections from layers containing aerosols, 4) reflections from regions of turbulence. The latter source is extensively discussed. (Author)

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203. Buldovskij, G.S. Meteorological Conditions for the Occurrence of Aircraft Bumpiness in the Stratosphere. National Lending Library for Science and Technology, Boston Spa (England). 20 Jul 1969, 24 p, refs Transl. into English from Tr. Nauchn.-Issled. Cent. SSSR, Gidromet. (Leningrad), v. 35. 1968 pp 36-48. Avail: Natl. Lending Library, Boston Spa, Engl., NLL-M-7728-(5828.4F)).

...Characteristic features of the stratosphere and their role in turbulence formation were studied for their disturbances of aircraft flights. Meteorological analyses of cases of turbulence in the stratosphere showed that turbulence developed mainly at levels near which there was a more or less sharp "kink" in the environment curve. Turbulence which produced moderate or severe bumpiness was observed at stratospheric heights up to 18 km. Analysis of upper air synoptic conditions during bumpiness in the stratosphere showed that turbulence formation occurred in upper frontal zones and regions of divergence.

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204. Burnham, J. Atmospheric Turbulence at Supersonic Transport Cruise Altitudes, Quart. J. Roy. Meteorol. Society, London, Vol. 95, No. 406, Oct 1969, pp 782-783. DAS M(05) R888q.

...The passenger in a supersonic transport is likely to have a noticeably smoother ride than he might expect on current subsonic aircraft. Although severe turbulence can occur at the altitudes at which he will fly, research done in recent years has led to a fairly good understanding of the situations which produce it, and means are available by which flight in likely affected areas can be avoided. (Author)

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205. Cooley, D.S. et al. Research to Determine Cloud and Synoptic Parameters Associated with Clear Air Turbulence Interim Report. Travelers Research Center, Inc., Hartford, Conn. Contract NAS12-699, NASA-CR-86229; Rept-7496-362, Jul 1969, 78 p, refs. Avail: CFSTI CSCLO4B.

...The relationships between Clear Air Turbulence (CAT) in the stratosphere and upper troposphere with meteorological variables, circulation data, and cloud features were studied. The principal turbulence data used were instrumented reports of CAT in the 45,000- to 70,000-ft layer. Approximate quantitative specifications were determined for ranges of parameters representing vertical variation of wind and temperature derived from rawinsonde observations. Large values of wind shear and negative values of temperature lapse rate or irregular lapse rate in the stratosphere were often associated with at least light to moderate intensity of CAT. Significant stratospheric CAT appears also to be associated with strong southwesterly flow and with banded and cumulonimbus clouds.  
(Author)

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206. Delov, I.A. Turbulence in the Upper Atmosphere at Altitudes of 90-110 Km and its Relationship to other Phenomena. Kiev. Universitet. Problemy Kosmicheskoy Fiziki. Sbornik (Kiev. University. Problems of Cosmic Physics), Compilation No. 1, 1966, pp 126-139. Foreign Technology Division Translation, Wright-Patterson AFB, Ohio. FTD-HT-23-761-68, 31 Jan 1969, 14 p, 7 figs, 12 refs. IPB Files.

...Systematic radiosonde measurements of turbulent motions and average wind speeds, (about 200,000 wind speed measurements), carried out at altitudes of 80 to 110 km (meteor zone) over Kharkov in the period from March 1962 to December 1963 are analyzed. Vertical profiles are constructed for the mean arithmetic values of the turbulent velocity gradient, the mean square turbulent wind speeds, the mean wind speeds, and the vertical dimensions of large-scale eddies to determine the dependence of these parameters on altitude, diurnal changes, seasonal variations, and long-period variations in relationship to other phenomena (solar activity, cosmic rays).  
(Author)

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207. Gebhard, J.B. Momentum, Heat Transfer, and Energy Spectra for Clear Air Turbulence in the Mid-Stratosphere. A Thesis submitted to the Faculty of the Univ. of Utah, Dept. of Meteor., Univ. of Utah, Aug 1969. 58 p. (in publication).

...An analysis of the Clear Air Turbulence in the mid-stratosphere indicates that the turbulence is generally characterized by a highly anisotropic field of turbulence with an intense lateral component of turbulence, associated with strong thermally-stable stratification.

Three categories of turbulence are considered. They are daytime, nighttime, and mountain-wave turbulence. The daytime turbulence is found to be associated with large turning in the wind direction with height and a Richardson number smaller than  $1/4$ . The nighttime and mountain wave turbulence are generally associated with small turning in the wind direction with height and a Richardson number greater than  $1/4$ .

Analyses of the momentum and heat transfer in regions of turbulence indicate that there is an upward transfer of the horizontal momentum, however, the vertical transfer of heat varies from case to case. (From Author's Abst.)

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208. Glover, Kenneth et al. Simultaneous Radar, Aircraft, and Meteorological Investigations of Clear Air Turbulence, in Proceedings of the Air Force Science & Engineering Symposium (1968) Vol. II, USAF, Arlington, Va. Report No. OAR-69-0004, Mar 1969, pp w1-w37. AD 686101.

...Simultaneous studies of the lower 15 km of the atmosphere by multi-wavelength radar, jet aircraft, and special radiosondes have been conducted at the JAFNA radar facility at Wallops Island, Va. Probably the most important result is that for the particular aircraft and velocity used in these experiments, every clear air radar echo above 3 km has been associated with aircraft reports of at least some perceptible degree of turbulence. Between the altitudes of 3 and 6 km, all CAT was detected by the radars; however, the ability of the radars to detect weak CAT decreased with increasing altitude and only the more intense turbulence was detected above 12 km. The indications are that more sensitive radars than those at Wallops Island should make it possible to detect most, if not all, of the significant CAT up to altitudes of at least 15 km. (Pt. Author Abst.)

209. Gunter, D.E. et al. Low Altitude Atmospheric Turbulence LO-LOCAT, Phases I & II. The Boeing Company, Wichita Div., Wichita, Kans. ASD-TR-69-12, Contract No. AF 33(615)-3724, Feb 1969, 418 p, 37 refs. AD 853299.

...This report presents procedures, analysis methods, and final results pertaining to the LO-LOCAT Program (Phases I & II). Approximately 300 hours of low-level (0-1,000 feet) turbulence and associated meteorological data recorded from Sep 15, 1966 to Dec 20, 1967 are analyzed. A model of the turbulence environment at low-level is presented in terms of gust velocity primary peaks, amplitude samples, RMS values, maximum values, and derived equivalent gusts. Mathematical expressions of turbulence spectra and scale-length statistics and correlations between atmospheric gust velocities and meteorological and geophysical phenomena are shown. The frequency spectrum of turbulence and the associated characteristics of isotropy, homogeneity, and stationarity are discussed. (Author)

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210. Jones, G.W. et al. Interim Analysis of Low Altitude Atmospheric Turbulence (LO-LOCAT) Data, Boeing Co., Wichita Div., Wichita, Kansas, TR 69-7, 15 Apr 1966-15 Sep 1967, Contract AF 33(615)-3724, Feb 1969. 129 p. AD 850301.

...The contents of this report described low-level critical air turbulence (LO-LOCAT) program accomplishments through 15 September 1967. These accomplishments cover the first year of the flight period. Utilizing four instrumented C131B aircraft, turbulence and meteorological data were obtained at absolute altitudes below 1,000 feet while flying over specified routes located in California, Colorado, Kansas, and New York. At the one-year point, approximately 600 hours of low-level turbulence data had been obtained. Analyses of these data show consistent agreement of gust velocity statistics as obtained from amplitude and peak samples. (Author)

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211. Kadlec, P.W. Atmospheric Temperature Changes Associated with High Altitude Turbulence, Eastern Air Lines, Inc., Miami, Fla. Jul 1969, 27 p, refs. Contract NAS4-1392. Avail: CFSTI CSCL04A.

...Previous research has indicated a correlation between atmospheric temperature changes and Clear Air Turbulence in the upper troposphere and lower stratosphere. Data from

## 211. (cont)

13XB-70 test flights and military training flights were analyzed in conjunction with information compiled on commercial flights to further explore the temperature-turbulence relationship. Three cases were discussed in detail in which significant high-altitude turbulence was encountered. This analysis revealed that horizontal temperature gradients of  $1.0^{\circ}\text{C}$  per 10 nautical miles depicted on meteorological constant pressure charts are indicative of moderate turbulence. Changes in isotherm orientation of  $45^{\circ}$  or more between two successive mandatory constant pressure levels appear to be related to similar intensities of Clear Air Turbulence. This information, together with vertical temperature profile criteria, may be useful in developing remote sensing devices to detect Clear Air Turbulence in the stratosphere. (Author)

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212. Kapovits, Albert. Severe Bumping of Aircraft Caused by High Altitude Atmospheric Turbulence, FTD, Wright-Patterson AFB, Ohio, Rep. No. FTD-HT-23-1149-68, Feb 1969, 12 p. AD 852150.

...A detailed discussion is presented for the occurrence of high-altitude turbulence which caused severe aircraft bumping on the Budapest-Frankfurt au Main route. Various hypotheses on turbulence analysis developed in recent years are taken into consideration in an effort to give Hungarian aeronautical meteorologists better insight into this phenomenon and to formulate an approach to successful analysis of turbulence cones in everyday forecasting. (Author)

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213. Litvinova, V.D. Daily Variation in the Turbulence Coefficient above Flat Terrain. Tsentral'Naya Aerologicheskaya Observatoriya. Trudy (Russian), FTD, Wright-Patterson AFB, Ohio. FTD-MT-24-41-69, 1969, 9 p. IPB Files.

...The results of aircraft investigations of atmospheric turbulence between 100 m to 3 km in the area around the city of Dolgoprudnyy carried out by the Central Aerological Observatory in 1940 are analyzed. A meteorograph and an accelerometer for recording acceleration in a vertical plane were installed on the aircraft. During the flights vertical soundings were made from areas at heights of 100, 300, 500, 1000, 1500, 2000, and 3000 m, and at the surface of the earth.

## 213. (cont)

The turbulent exchange (K) was computed. Individual flights analyzed with the aid of graphs of the vertical profile of the turbulence coefficient and the daily variation of the turbulence coefficient at different altitudes. (Author)

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214. MacPherson, J.U. and Lum, K. Instrumentation of an RB-57F to Measure High-Altitude Turbulence Encounters, National Aeronautical Establishment, Ottawa, Ont. Report No. NAE-LR-522, Mar 1969, 24 p. AD 690304.

...The National Aeronautical Establishment has installed a turbulence instrumentation package and memory recorder on a USAF RB-57F weather reconnaissance aircraft at Kirtland Air Force Base, New Mexico. The object of the project named 'COLDSCAN' is to record turbulence encounters and temperature changes on routine weather patrol and training flights at altitudes above 50,000 feet. A description of the instrumentation system and its operation is presented along with example data from two of the first project flights. These initial results are most significant for the magnitudes of the temperature gradients encountered near 60,000 feet. (Author)

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215. Nathan, N.H. et al. Airborne Turbulence Measuring System Design Study, Instrumentation Laboratory, Mass. Institute of Tech. (MIT), Cambridge, Mass., Report No. R-640, Jun 1969. 129 p. DAS M(051) M4145r R-640.

...This report covers work performed by personnel of the Massachusetts Institute of Technology Instrumentation Laboratory under contract to Woods Hole Oceanographic Institution. The objective of the work has been to join with personnel from Woods Hole and conduct a design and feasibility study for an aircraft turbulence measurement system based on the Pace II inertial navigation system. An advanced state-of-the-art system is proposed consisting of a gust-data reference system interfaced with a remote meteorological instrument package. The reference system measures the position, velocity, and attitude of the gust probe mount with respect to the earth and records this data and the meteorological instrument data on a real-time basis. An optical measurement unit, conceptually designed under the contract, references the externally-located gust probe to the inboard

215. (cont.)

inertial measurement unit. The system mechanization, although oriented towards use of the WHOI C-54 aircraft and an available 15-foot vertical mast, is flexible enough not to be restricted to this particular aircraft or this particular configuration. In addition, the reference system can be used independently for other airborne applications requiring accurate position, velocity, and attitude data. Analysis covers system design, including velocity compensation of the gust-probe data, and a technique for accurately aligning the inertial measurement unit in the aircraft prior to flight. (Author)

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216. Prophet, David T. Clear Air Turbulence in the Stratosphere above a Squall Line. Lockheed-Calif. Co., Burbank, Calif. Conference on Severe Local Storms, 6th, Chicago, Apr 8-10, 1969, Preprint of papers presented at the Conference. (Boston, American Meteorological Society), 1969. pp 363-366. Figs, table, refs. DAS M15.3 C748pa.

...Aircraft turbulence data obtained in the lower stratosphere above a squall line are analyzed in terms of observed irregularities in radiosonde ascensional rates and mesoscale meteorological features associated with the squall line over the special meso-network of radiosonde stations in Oklahoma. On this occasion, the irregularities in radiosonde ascensional rates in the stratosphere are shown to be small and less than 1 m/sec prior to the arrival of the squall line. However, after thunderstorms appeared over the meso-networks, some soundings displayed relatively large irregularities amounting to 2 to 4 m/sec. These values are shown to be comparable to the aircraft vertical gust data obtained over nearby thunderstorms. (Author)

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217. Tatarskii, V.I. Atmospheric Turbulence; Foreign Technology Div., Wright-Patterson AFB, Ohio. Edited Trans of Zemlya i Vselennaya (USSR) Vol. 4, No. 2, pp 43-46, 1968, Rpt. No. FTD-MT-24-45-69, 23 May 1969, 13 p. AD 693842.

...In this conversational approach to the effects of atmospheric turbulence, the atmosphere is compared to a tube filled with water containing some visible particles which can be observed as they are affected by turbulent motion. The effects of turbulence are seen in the action of an airplane when pressure on the wings is uneven, causing a bumpy ride. Turbulence has a great

effect in preventing heavy gases, smoke, radioactive waste, and such substances from collecting at the surface of the earth. It is also seen to have great influence on the heat cycle, refraction, propagation of radio waves, and astronomical observations, causing stars to appear to twinkle.  
(Author)

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218. Vasilev, A.A. An Analysis of Clear Air Turbulence Using Radiosonde Data. Transl into English from Tr Nauchn-Issled. Cent. SSSR, Gidromet (Leningrad) No. 35, 1968, 20 Jul 1969, 32 p, refs, pp 13-28. Avail: Natl. Lending Library, Boston Spa, England (NLL-M-7726-(58284F)).

...Clear Air Turbulence (CAT) forecasting is studied. The difficulties involved are: 1) small-scale atmospheric processes, distinguished by intense turbulence, from a few meters to a kilometer in thickness and from a few kilometers to hundreds in horizontal length and variable in time and space; 2) the subject nature of estimating the severity of the turbulence. Optional predictors of turbulence for an objective analysis and turbulence forecasting from radiosonde data are chosen for this investigation. It is concluded that the best form of analyses are pilot reports of turbulence on regular flights. Turbulence forecasts by means of simply moving the actual report eastward using the best meteorological parameters are considered highly reliable.

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219. Vasilev, A.A. An Assessment of the Effectiveness of Synoptic Criteria for the Existence of Clear Air Turbulence. Transl. into English from Tr. Nauchn-Issled. Cent. SSSR, Gidromet (Leningrad) No. 35, 1968, pp 29-35. Avail Natl. Lending Library, Boston Spa. England, NLL-M-7732-(5828-4F).

...An analytical method for squaring off turbulent and non-turbulent areas in the upper troposphere is used to test the predictive ability of synoptic criteria. Four observation series were used to determine the frequency of turbulent squares, the frequency of nonturbulent squares, and the probability of bumpiness for 11 synoptic models. Statistical distributions of these frequencies revealed that none of the synoptic models was adequate to forecast turbulence morphological criteria were essential for this achievement. Findings are 1) bumpiness zones produced by turbulence could develop in any of the synoptic criteria, 2) turbulence is observed most frequently in a diffluent contour zone, on the cyclonic

219. (cont)

side of a jet stream, or the axis of a trough, and formed in ridges almost as often as in troughs. 3) Bumpiness formation is greatest in troughs, and sometimes unassociated with any pressure field characteristics, but instead with vertical wind shear zones. Synoptic and quantitative criteria combined were recommended in the analysis of bumpiness.

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220. Zimmerman, Samuel P. Turbulent Atmospheric Parameters Determined from Radio Meteor Trails. Hanscom Field, Bedford, Mass., Air Force Cambridge Research Labs., Office of Aerospace Research, U.S. Air Force, 1969. 14 p. (U.S. Air Force. Office of Aerospace Research. Environmental Research Papers, No. 300) AFCRL-69-0162. DAS M(05) U58en no. 300.

...The application of turbulence theory to atmospheric structure revealed by radio meteor trails clearly demonstrates that Batchelor and Obukoff's structure function for isotropic turbulence explains some of the observed relations. From these measurements, parameters such as the rate of viscous dissipation, the eddy intensity, the local eddy Reynolds number describing the turbulence, and turbulent diffusion coefficient are determined. An estimate of the rate at which turbulence extracts wind energy from the diurnal tide is given.

The results of the parametric study suggest very strongly that the universal range of the turbulent spectrum, in the upper atmosphere, contains little or no energy extending into the inertial subrange, but lies for the most part near the viscous (high wave-number) region. (Author)

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This bibliography contains 220 references on clear air turbulence, with annotations. These references are listed alphabetically by author by year. The references for the most part refer to turbulence as it appears in the free atmosphere, and represent views from authors/agencies worldwide.			

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